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USAARL Report No. 93-13

United States Army
Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-5292

User's Manual for BRNSIM/BURNSIM: A Burn Hazard Assessment Model

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February 1993

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	1993 February	Interim - 1980-1992

4. TITLE AND SUBTITLE

User's Manual for BRNSIM/BURNSIM: A Burn Hazard Assessment Model

5. FUNDING NUMBERS

PE - 62202A
PR - 7231
TA - 723124
WU - 72312403

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Crew Systems Directorate
Armstrong Laboratory
Human Systems Center
Wright-Patterson AFB OH 45433-6573

U.S. Army Aeromedical
Research Laboratory
Box 620577
Fort Rucker AL 36362
-0577

8. PERFORMING ORGANIZATION REPORT NUMBER

USAARL Report No. 93-13

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Medical Research & Development Command
Fort Detrick MD 27514-5000

Human Systems Center
Brooks AFB TX 78235-5000

Defense Nuclear Agency
RAAP
Washington DC 20305-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES This report is a product of a program supported by both the U.S. Army Medical R&D Command through its U.S. Army Aeromedical Research Laboratory at Fort Rucker) and the U.S. Air Force (Materiels Laboratory, Life Support SPO, and Armstrong Laboratory) from 1970-1992. The senior author has been the principal investigator throughout.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

BURNSIM is an interactive computer model which runs on DEC minicomputers (PDP 11 and VAX), Macintosh and IBM compatible PCs. The model is based on the work of Moritz and Henriques at Harvard, the Surgery Department at University of Rochester; Alice Stoll at Naval Air Development Center and Knox et al. at the U.S. Army Aeromedical Research Laboratory. Its development has been funded by the U.S. Army, U.S. Air Force, and Dr. Knox. The model predicts time to pain and burn depth when bare skin is exposed to any arbitrary time history of heat flux. It predicts burn depth with reasonable accuracy for pig and human skin. A software module to include clothing between the thermal source and the skin has been developed but not integrated with BURNSIM and has not been validated. By using sensors to measure heat flux behind fabric it has been possible to use BURNSIM to evaluate the insulating effect of clothing. BURNSIM has been used in the last several years to assess the burn hazard associated with rocket plumes in side-by-side ejection seats, shoulder launched weapons, nuclear flash and live fire. This manual provides information on model development, its installation and use on a PC.

14. SUBJECT TERMS

Burns
Computer model
Thermal protection
Burn hazard prediction

15. NUMBER OF PAGES

70

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

Acknowledgments

The senior author wishes to express his gratitude to the many colleagues who have contributed to the development of BURNSIM. Drs. Stanley C. Knapp, Thomas L. Wachtel, and Chap McCahan have worked on the project from the beginning in 1970 when we were all stationed at the U.S. Army Aeromedical Research Laboratory. Dr. Knapp had started the project to study postcrash fires with funding from various sources including the U.S. Army Medical Research and Development Command and the USAF Life Support Systems Program Office at Wright-Patterson Air Force Base. Dr. Cal Lum helped during the data collection phase in 1972. Dr. Daniel D. Reneau and his graduate student, Nelson O'Young, contributed the basic section of code to calculate the conductive heat transfer. Randy Nockton and Chet Ellis contributed additional software development including tape reading routines, statistical analysis programs and a database to manage the data. Dr. Charles Yuell, a pathologist at the Rochester School of Medicine, helped clarify the burn depth grading scheme and even found some of the original porcine skin samples from earlier burn studies at Rochester. Mr. Chris Perry and CPT Dena Bonetti have worked with BURNSIM for the past 3 years at the Armstrong Laboratory and have contributed to the current effort supported by the Defense Nuclear Agency. Part of this effort is the PC version of BURNSIM for which CPT Dena Bonetti is largely responsible. Funding for this effort has come from the U.S. Army Medical R&D Command, Defense Nuclear Agency, and the U.S. Air Force without which BURNSIM would not have been developed.

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Background

BRNSIM (or BURNSIM as it is now called) is a computer model which allows the user to convert heat flux incident to bare skin to a predicted burn depth. The requirement for such a model arose when there was a need to quantify the thermal protective properties of new flight suits. Techniques employed in the 1960s and very early 1970s did not predict the full range of burns from no burn to full thickness and failed to take into account both initial conditions of the skin and its adaptive behavior when heated.

Since the late 1960s, the U.S. Army Aeromedical Research Laboratory (USAARL) at Fort Rucker, Alabama, has been involved in quantifying the burn hazard associated with post crash fires and the protective capability of flight clothing[1]. USAARL staff (including the author) conducted a number of field studies using burning helicopters to establish the severity and time course of post crash fires (Knapp and Knox, 1982). They also 1) built and used two fire simulators to study the effect of simulated postcrash fires on pigs as an analog for man (Knox et al., 1978b), 2) placed fabrics between the fire and the pigs to study their protective capability (Knox et al., 1980), 3) assembled a large porcine (pig) burn database using this bioassay method (Knox, 1979a), and 4) developed the model, BRNSIM, to decrease the workload associated with using the bioassay method to assess fabric protective capabilities (Knox, 1979b).

The starting point for building BRNSIM (short for burn simulation) was the work of Alice Stoll who based her model on Moritz and Henriques' damage integral (Henriques, 1947). She had collected data from human volunteers on the time/heat flux relationships resulting in threshold transepidermal necrosis. This burn is represented by minor blister formation. To explain her results she added a consideration of damage occurring during cooling as well as during the heating phase (Figure 1). Stoll chose the constants (Stoll and Greene, 1959) in her model to fit her human data on threshold burns; more severe burns were not at first considered. Later Weaver and Stoll (1969) proposed an extension of Stoll's first model to include more severe burns without experimental basis.

The first model to come out of the USAARL program was that of Art Takata of IITRI (Takata, 1974) who worked for USAARL as a contractor. He started with Stoll's approach and added water boiling as a way of handling blister formation. He then adjusted the constants ($P, \Delta E$) (see equation (7) in Appendix A) to more accurately predict USAARL's data on more severe porcine burns.

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[1]The development of this model and the work upon which it is based has been funded by U.S. Army Medical Research & Development Command, Fort Detrick; U.S. Air Force Life Support Systems Program Office and Armstrong Laboratory, Wright-Patterson Air Force Base, Ohio; Defense Nuclear Agency, Washington D.C., and as a personal project by the primary author.

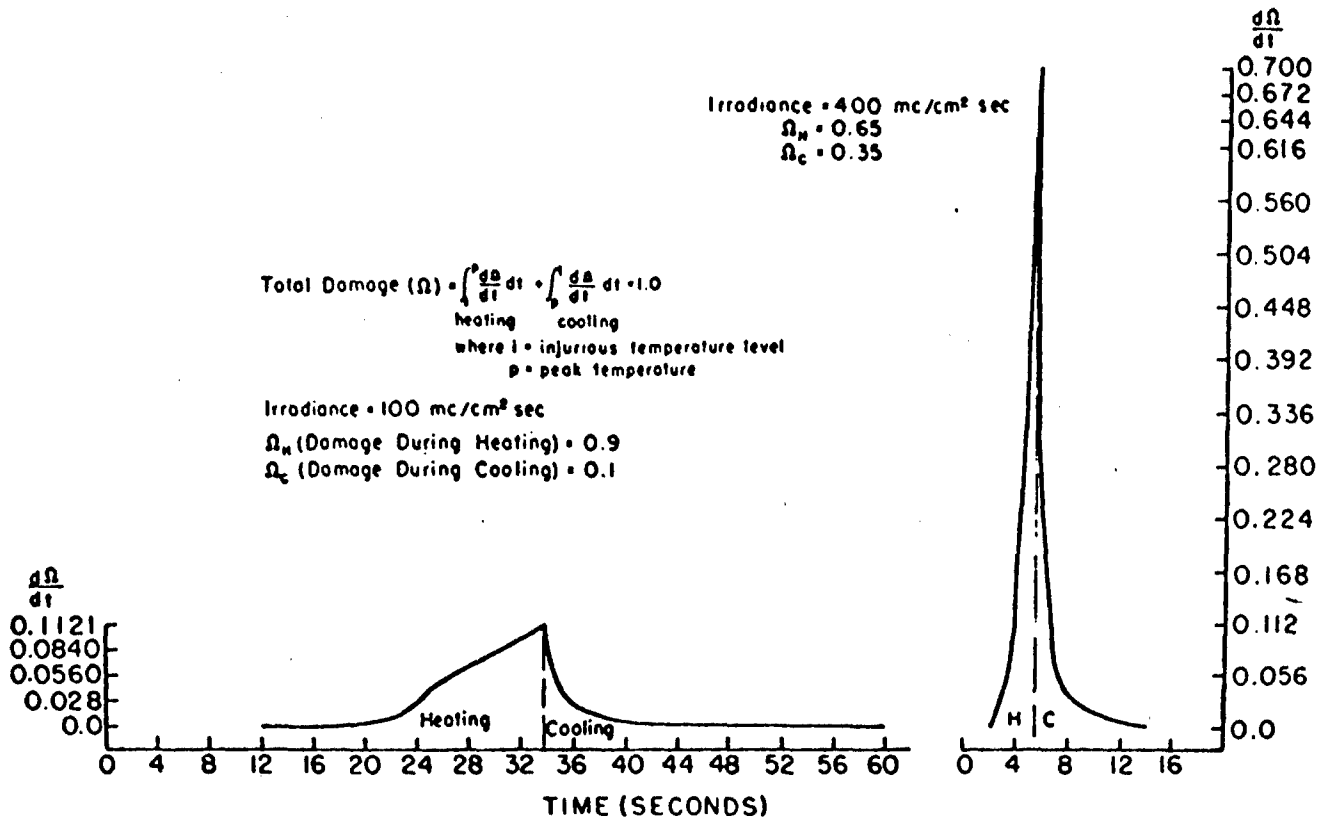

Figure 1. Tissue damage integral indicative of the blister endpoint (Stoll and Chianta, 1971)

The current BURNSIM model builds on these earlier efforts (Henriques, 1947; Weaver and Stoll, 1969; Mehta and Wong, 1973; Morse et al., 1973; and Takata, 1974). It is an interactive model written in both FORTRAN and ZBASIC and runs on PDP 11/40, 11/03, 11/24, VAX 11/780, Macintosh, and IBM compatible PCs.

Model description

BURNSIM considers the skin to be represented as 12 chunks or nodes (See Figure 2). Seven additional nodes can be inserted between the first and second nodes when exposures are mild and burn damage is likely to be shallow (Figure 2). BURNSIM solves the Fourier heat conduction equation to find temperature as a function of time at each node. Then total damage at each node is found by computing the damage integral at each depth. The transition between normal and damaged skin is defined as that depth where the damage integral is equal to one. For a more detailed description of the mathematics of BURNSIM consult Appendix A. BURNSIM source code (FORTRAN version) can be found in Appendix B.

Getting started

BURNSIM has been supplied to you in either source or compiled form. The following instructions are intended to help you use the model. The instructions and comments are based, in part, on feedback received from several users who have attempted to get started without the benefit of this manual. If you have problems using BURNSIM please do not hesitate to call the author at DSN 785-3931 or (513) 255-3931. Future versions of this manual will incorporate your comments and suggestions so that we may continue to improve BURNSIM and to distribute updated versions to the users.

The first step is to load the code for the model into your computer from the medium provided. This step has many versions. Only one example is given because it is assumed that if you are using this model you are sufficiently computer literate to load and compile the source code on your system.

```
PC Example: BURNSIM.FOR, REN12.DAT on floppy disk.
 To run off hard disk:
Set default disk drive to a:
Put diskette in a:
Type  DIR (rtn)
BURNSIM.FOR   REN12.DAT      FLUX.DAT    BURNSIM.EXE
A>CD C:
C>MD C:\BURNSIM
C>CD C:\BURNSIM
C>COPY a:*.* c:
C:\BURNSIM>DIR
BURNSIM.FOR    REN12.DAT     FLUX.DAT    BURNSIM.EXE
C:\BURNSIM>
```

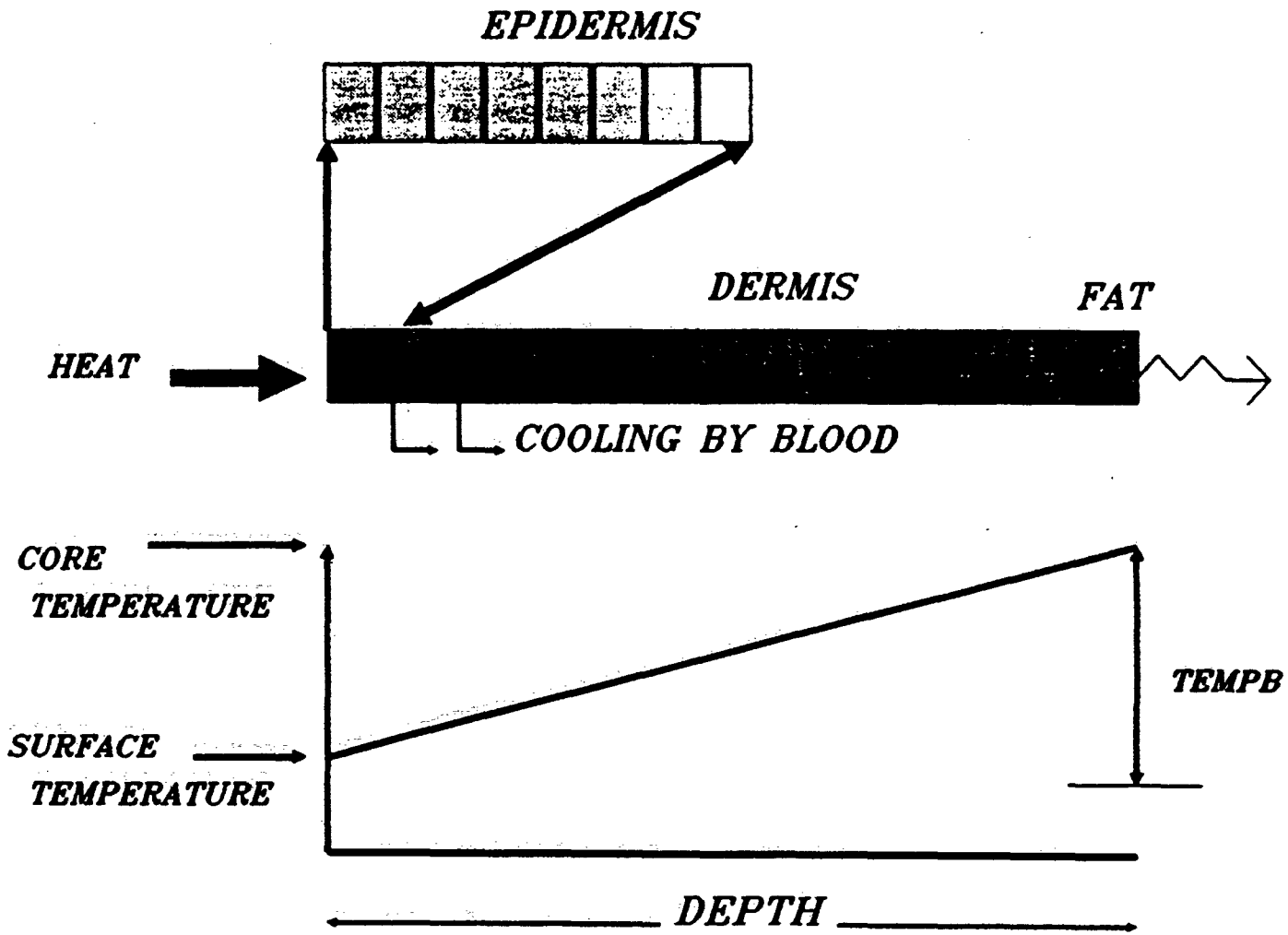

Figure 2. Skin representation

At this point you have made a directory on your hard disk for BURNSIM and copied the files from the floppy to the new directory. The file REN12.DAT contains the initial values of all the variables which are changeable within BURNSIM. Some of these values such as the conductivity and heat capacity for each node can only be changed by creating a new REN12.DAT with an editor or word processing program (see Appendix C for the layout of REN12.DAT). The model expects a flat ASCII file, so if you use a word processor, save the file as an ASCII text file and not a document. Other values such as exposure time (ETIME) can be changed interactively as described below.

To run BURNSIM invoke the command for your system, e.g. RUN BURNSIM or BURNSIM. You will next see the following on the screen:

BURNSIM <CR>

The first screen that you see is shown below:

> WELCOME TO BURNSIM. TO BEGIN RUNNING THE PROGRAM, BURNSIM FIRST NEEDS TO KNOW THE NAME OF THE FILE THAT YOU WANT TO STORE THE OUTPUT DATA IN. THIS FILE WILL CONTAIN ALL OF THE INPUT PARAMETERS AS WELL AS THE OUTPUT FOR EACH ITERATION THE MODEL PERFORMS. THIS FILE CAN BE CALLED ANYTHING UP TO EIGHT CHARACTERS LONG.
>
> PLEASE ENTER A NAME FOR THE OUTPUT FILE: **OUTFILE** <CR>

The next screen is shown below:

> NEXT BURNSIM WILL SHOW YOU THE PRESENT INPUT PARAMETERS. UNDER THE LIST OF PARAMETERS YOU WILL SEE A QUESTION ASKING IF YOU WISH TO CONTINUE. IF YOU WANT TO EXIT THE PROGRAM AT THAT POINT, TYPE N. OTHERWISE TYPE Y.
>
> TO CONTINUE ON TO THE LIST OF PARAMETERS TYPE A <CR>.

The following screen will appear:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMPI0 = 32.5000	DENS = 1.00000	Q1 = 3.54000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.5000	ABSORB = .61300	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 3.02000	ITIME = 80.00000	NXTRA = 0
BLOOD = .00100		
APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

DO YOU WISH TO CONTINUE? TYPE Y OR N Y <CR>

Answer yes (Y) to continue and you will be presented with the following choices:

TYPE THE NUMBER OF THE FUNCTION BELOW THAT YOU
WISH TO PERFORM.

CHOOSE A FUNCTION NUMBER:
1 - CHANGE SELECTED INITIAL VALUES
2 - NO CHANGES--CONTINUE RUNNING THE PROGRAM
3 - EXIT

PLEASE ENTER THE FUNCTION NUMBER: 1 <CR>

Choose #1 to change the set up values. This will give you the following screen:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMPI0 = 32.5000	DENS = 1.00000	Q1 = 3.54000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.5000	ABSORB = .61300	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 3.02000	ITIME = 80.00000	NXTRA = 7
BLOOD = .00100		
APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

DO YOU WANT TO MAKE ANY CHANGES? Y OR N Y

Answer yes (Y) here to change the input values using the following screen:

PICK A NUMBER

1=TEMPI0	8=ETIME
2=DENS	9=PL1
3=Q1	10=PLN1
4=BL	11=PL2
5=AK	12=PLN2
6=JINC	13=DE1
7=TEMPB	14=DE2

15=ITIME 16=ABSORBTIVITY

17=BOIL 18=EXTRA NODES

19=BLOOD 20=APL1

21=APLN1 22=APL2

23=APLN2 24=ADE1 25=ADE2

Choose the number representing the parameter you wish to change. The definition of these parameters is in Table I. For example, set up one of Stoll's published cases (Weaver and Stoll, 1969). In this case, the human skin was exposed for 5.6 seconds at 0.4 cal/cm^2-sec. The skin was blackened with India ink to set the absorbtivity at 94 percent. Start by choosing #3 to set the incident flux level, Q1. The model responds with:

```
ENTER THE FLUX FILE NAME (TYPE A <CR> IF NO FILE
IS TO BE USED):  <CR>
```

Since Stoll's case has a constant flux value, type a ⟨CR⟩ and the following will appear on the screen:

```
CONSTANT Q-VALUE =    3.5400000    INPUT NEW VALUE:  0.4 <CR>
```

The old value was 3.54000 and the new value entered was 0.4 cal/cm^2-sec.

****

If you do later simulations where you wish to read in a file of varying flux values instead of using a constant flux value, type the name of the flux file in response to the following statement:

```
ENTER THE FLUX FILE NAME (TYPE A <CR> IF NO FILE
IS TO BE USED): FLUX.DAT
```

The file **FLUX.DAT** is the example flux file given on the disk. When creating flux files to be read into BURNSIM, remember that the file name can be no more than eight characters in length including the .DAT ending. Also the file must contain only one column of data, the flux data, in units of cal/cm^2-sec. The number of points in the flux file and the sample interval between points must be known, too.

Continue to input responses to the following statements concerning the flux file as they appear on the screen:

```
ENTER FLUX ID (UP TO 8 CHARACTERS):  IDFLUX ⟨CR⟩
```

The FLUX ID can be any combination of 8 characters.

```
ENTER THE NUMBER OF POINTS IN THE FLUX PROFILE: 100 ⟨CR⟩
```

The maximum number of points that can be read in is 600.

ENTER THE SAMPLE INTERVAL IN SECONDS: **0.1** ⟨CR⟩

*** Note: When using a flux file for the incident flux, the exposure time (ETIME) variable must be set equal to the number of points in the flux file minus one times the sample interval in seconds. For this example, ETIME = (100 - 1) x (0.1) = 9.9 seconds.

****

The next screen is shown below:

SKIN DIFFUSION DATA
INPUT PARAMETER LIST

TEMPI0 = 32.5000	DENS = 1.00000	Q1 = .40000
BL = .22000	AK = .01000	JINC = 12
TEMPB = 4.5000	ABSORB = .61300	BOIL = 100.15000
PL1 = 1.46000	PLN1 = 147.37000	DE1 = 50000.0
PL2 = 2.24000	PLN2 = 239.47000	DE2 = 80000.0
ETIME = 3.02000	ITIME = 80.00000	NXTRA = 7
BLOOD = .00100		
APL1 = .78000	APLN1 = 285.52000	ADE1 = 93534.9
APL2 = .60000	APLN2 = 117.43000	ADE2 = 39109.8

DO YOU WANT TO MAKE ANY CHANGES? Y OR N **Y**

Answer yes (Y) here to change the next input value using the following screen:

PICK A NUMBER

1=TEMPI0	8=ETIME
2=DENS	9=PL1
3=Q1	10=PLN1
4=BL	11=PL2
5=AK	12=PLN2
6=JINC	13=DE1
7=TEMPB	14=DE2
15=ITIME	16=ABSORBTIVITY
17=BOIL	18=EXTRA NODES
19=BLOOD	20=APL1
21=APLN1	22=APL2

```
        23=APLN2            24=ADE1                 25=ADE2

18 <CR>

    THE NUMBER OF EXTRA NODES IS:   0  INPUT NEW VALUE: 7 <CR>

 ENTER NEW VALUES SEPARATED BY A COMMAS, OR A <CR>
 IF THE PROGRAM IS TO CALCULATE VALUES. 25.,50.,75.,100.,125.,150.,175.
```

The next screen is shown below:

```
                          SKIN DIFFUSION DATA
                          INPUT PARAMETER LIST

TEMPI0 =  32.5000      DENS =   1.00000        Q1 =    .40000
BL =     .22000        AK =     .01000         JINC = 12
TEMPB =   4.5000       ABSORB =    .61300      BOIL =  100.15000

PL1 =    1.46000       PLN1 = 147.37000        DE1 =    50000.0
PL2 =    2.24000       PLN2 = 239.47000        DE2 =    80000.0
ETIME =  3.02000       ITIME =  80.00000       NXTRA =  7
BLOOD =   .00100

APL1 =    .78000       APLN1 = 285.52000       ADE1 =    93534.9
APL2 =    .60000       APLN2 = 117.43000       ADE2 =    39109.8

THE EXTRA NODES ARE:  25.0  50.0  75.0  100.0  125.0  150.0  175.0

          DO YOU WANT TO MAKE ANY CHANGES? Y OR N Y
```

Answer yes (Y) here to change the next input value using the following screen:

```
     PICK A NUMBER

        1=TEMPI0            8=ETIME

        2=DENS              9=PL1
        3=Q1                10=PLN1

        4=BL                11=PL2
        5=AK                12=PLN2

        6=JINC              13=DE1
        7=TEMPB             14=DE2

        15=ITIME            16=ABSORBTIVITY
        17=BOIL             18=EXTRA NODES

        19=BLOOD            20=APL1
        21=APLN1            22=APL2
```

```
        23=APLN2            24=ADE1                 25=ADE2

19 <CR>

  THE VALUE FOR BLOOD IS:  .00100  INPUT NEW VALUE:  0.0007 <CR>
```

The next screen is shown below:

```
                          SKIN DIFFUSION DATA
                          INPUT PARAMETER LIST

TEMPIO =  32.5000      DENS =   1.00000        Q1 =    .40000
BL =     .22000        AK =     .01000         JINC = 12
TEMPB =   4.50000      ABSORB =    .61300      BOIL =  100.15000

PL1 =    1.46000       PLN1 = 147.37000        DE1 =    50000.0
PL2 =    2.24000       PLN2 = 239.47000        DE2 =    80000.0
ETIME =  3.02000       ITIME =  80.00000       NXTRA =  7
BLOOD =   .00070

APL1 =    .78000       APLN1 = 285.52000       ADE1 =    93534.9
APL2 =    .60000       APLN2 = 117.43000       ADE2 =    39109.8

THE EXTRA NODES ARE:  25.0  50.0  75.0  100.0  125.0  150.0  175.0

          DO YOU WANT TO MAKE ANY CHANGES? Y OR N Y
```

Answer yes (Y) here to change the next input value using the following screen:

```
   PICK A NUMBER

        1=TEMPIO            8=ETIME

        2=DENS              9=PL1
        3=Q1                10=PLN1


        4=BL                11=PL2
        5=AK                12=PLN2
        6=JINC              13=DE1
        7=TEMPB             14=DE2

        15=ITIME            16=ABSORBTIVITY
        17=BOIL             18=EXTRA NODES

        19=BLOOD            20=APL1
        21=APLN1            22=APL2

        23=APLN2            24=ADE1                 25=ADE2

8 <CR>
```

THE VALUE FOR ETIME IS: 3.02000 INPUT NEW VALUE: **5.6 <CR>**

The next screen is shown below:

```
                        SKIN DIFFUSION DATA
                        INPUT PARAMETER LIST

TEMPI0 =  32.5000      DENS =   1.00000        Q1 =    .40000
BL =     .22000        AK =     .01000         JINC = 12
TEMPB =   4.50000      ABSORB =    .61300      BOIL =  100.15000

PL1 =    1.46000       PLN1 = 147.37000        DE1 =    50000.0
PL2 =    2.24000       PLN2 = 239.47000        DE2 =    80000.0
ETIME =  5.60000       ITIME =  80.00000       NXTRA =  7
BLOOD =   .00070

APL1 =    .78000       APLN1 = 285.52000       ADE1 =    93534.9
APL2 =    .60000       APLN2 = 117.43000       ADE2 =    39109.8

THE EXTRA NODES ARE:  25.0  50.0  75.0  100.0  125.0  150.0  175.0

          DO YOU WANT TO MAKE ANY CHANGES? Y OR N Y
```

Answer yes (Y) here to change the next input value using the following screen:

```
   PICK A NUMBER

        1=TEMPI0            8=ETIME

        2=DENS              9=PL1
        3=Q1                10=PLN1

        4=BL                11=PL2
        5=AK                12=PLN2

        6=JINC              13=DE1
        7=TEMPB             14=DE2

        15=ITIME            16=ABSORBTIVITY
        17=BOIL             18=EXTRA NODES

        19=BLOOD            20=APL1
        21=APLN1            22=APL2

        23=APLN2            24=ADE1                 25=ADE2
```

16 <CR>

THE VALUE FOR ABSORB IS: 0.61300 INPUT NEW VALUE: **0.94 <CR>**

The next screen is shown below:

```
                    SKIN DIFFUSION DATA
                    INPUT PARAMETER LIST

TEMPI0 =  32.5000      DENS =   1.00000        Q1 =     .40000
BL =     .22000        AK =     .01000         JINC = 12
TEMPB =   4.50000      ABSORB =    .94000      BOIL =  100.15000

PL1 =    1.46000       PLN1 = 147.37000        DE1 =    50000.0
PL2 =    2.24000       PLN2 = 239.47000        DE2 =    80000.0
ETIME =   5.60000      ITIME =  80.00000       NXTRA =  7
BLOOD =    .00070

APL1 =     .78000      APLN1 = 285.52000       ADE1 =    93534.9
APL2 =     .60000      APLN2 = 117.43000       ADE2 =    39109.8

THE EXTRA NODES ARE:  25.0  50.0  75.0  100.0  125.0  150.0  175.0

          DO YOU WANT TO MAKE ANY CHANGES? Y OR N N
```

At this point all of the input values for Stoll's example case have been set, so the answer here is no (N).

****

NOTE: If you inadvertently answer yes (Y) to make changes, and then decide not to make any, type a <CR> to exit the "PICK A NUMBER" menu, and the following question will appear:

```
DO YOU WISH TO CONTINUE? TYPE Y OR N Y <CR>
```

Type yes (Y) to continue on with the present run.

****

Now that the correct parameters are set up, select #2 to proceed:

```
TYPE THE NUMBER OF THE FUNCTION BELOW THAT YOU
WISH TO PERFORM.

     CHOOSE A FUNCTION NUMBER:
          1 - CHANGE SELECTED INITIAL VALUES
          2 - NO CHANGES--CONTINUE RUNNING THE PROGRAM
          3 - EXIT

     PLEASE ENTER THE FUNCTION NUMBER: 2 <CR>
```

You are now ready to run the program. BURNSIM will ask you for some file names in which to store the data and summaries.

```
ENTER THE MODEL NAME OR DESCRIPTION (UP TO 80
CHARACTERS).  THIS INFORMATION WILL BE USED
AS A TITLE ON THE SUMMARY PAGE.
```

TEST OF A. STOLL'S .4CAL 5.6 SEC CASE FOR USER'S MANUAL <CR>

The following screen appears:

```
NOW ENTER THE SUMMARY FILENAME (UP TO 8
CHARACTERS).  THIS FILE WILL CONTAIN A
SUMMARY OF THE SIMULATION.  SUM1 ⟨CR⟩
```

Any name up to 8 characters can be used.

The next screen then appears:

```
NOW ENTER THE TEMPERATURE FILE (UP TO 8 CHARACTERS).
THIS FILE WILL CONTAIN A LIST OF THE TEMPERATURES
AT THE VARIOUS NODES DURING THE SIMULATION.  TFILE1 ⟨CR⟩
```

Any name up to 8 characters can be used.

While calculating, the model prints the following on the screen:

```
  T=        XTIME=                              TIME=  0.000000
   32.50       0.0000E+00
   32.91       0.0000E+00
   33.32       0.0000E+00
   33.73       0.0000E+00
   34.14       0.0000E+00
   34.55       0.0000E+00
   34.95       0.0000E+00
   35.36       0.0000E+00
   35.77       0.0000E+00
   36.18       0.0000E+00
   36.59       0.0000E+00
   37.00       0.0000E+00
BLUD =.00000

  T=        XTIME=                              TIME=  0.010000
   32.96       0.0000E+00
   32.92       0.0000E+00
   33.32       0.0000E+00
   33.73       0.0000E+00
   34.14       0.0000E+00
   34.54       0.0000E+00
   34.95       0.0000E+00
   35.36       0.0000E+00
   35.77       0.0000E+00
   36.18       0.0000E+00
   36.59       0.0000E+00
   36.99       0.0000E+00
BLUD =.00000
```

```
  T=        XTIME=                                TIME=   1.000000
   44.40       0.0000E+00
   40.02       0.0000E+00
   37.25       0.0000E+00
   35.71       0.0000E+00
   35.03       0.0000E+00
   34.89       0.0000E+00
   35.04       0.0000E+00
   35.33       0.0000E+00
   35.67       0.0000E+00
   36.01       0.0000E+00
   36.32       0.0000E+00
   36.64       0.0000E+00
BLUD =.00003

  T=        XTIME=                                TIME=   2.000000
   49.19       0.0000E+00
   44.62       0.0000E+00
   41.24       0.0000E+00
   38.86       0.0000E+00
   37.29       0.0000E+00
   36.36       0.0000E+00
   35.90       0.0000E+00
   35.76       0.0000E+00
   35.83       0.0000E+00
   36.02       0.0000E+00
   36.27       0.0000E+00
   36.60       0.0000E+00
BLUD =.00007
.
. part of the sequence omitted to save space.
.
\/
  T=        XTIME=                                TIME= 13.000000
   44.50       0.0000E+00
   44.44       0.0000E+00
   44.32       0.0000E+00
   44.13       0.0000E+00
   43.81       0.0000E+00
   43.37       0.0000E+00
   42.81       0.0000E+00
   42.13       0.0000E+00
   41.36       0.0000E+00
   40.50       0.0000E+00
   39.59       0.0000E+00
   38.43       0.0000E+00
BLUD =.00045

  T=        XTIME=                                TIME= 14.000000
   44.02       0.0000E+00
   43.97       0.0000E+00
   43.86       0.0000E+00
```

```
   43.70       0.0000E+00
   43.43       0.0000E+00
   43.03       0.0000E+00
   42.52       0.0000E+00
   41.90       0.0000E+00
   41.17       0.0000E+00
   40.36       0.0000E+00
   39.49       0.0000E+00
   38.38       0.0000E+00
BLUD =.00049

  T=        XTIME=                                TIME= 14.040000
   44.00       0.0000E+00
   43.95       0.0000E+00
   43.85       0.0000E+00
   43.69       0.0000E+00
   43.41       0.0000E+00
   43.02       0.0000E+00
   42.51       0.0000E+00
   41.89       0.0000E+00
   41.17       0.0000E+00
   40.36       0.0000E+00
   39.48       0.0000E+00
   38.38       0.0000E+00
BLUD =.00049
```

At the conclusion of the calculations, the following information appears on the screen:

```
    W=1 LIES ABOVE NODE 2.  INTERCOLLATING VALUES OF D
    AND W COMPUTED FROM INTERPOLATED VALUES OF D AND
    TEMPERATURE.

MAXIMUM TEMPERATURE =   60.056

THRESHOLD DEPTH =    104.6

FINAL TIME =   14.04

TIME TO PAIN =   1.59

                TYPE A <CR> TO CONTINUE.  <CR>
```

The next screen asks if you want to reformat the file so that it can be brought into the HARVARD GRAPHICS shell to make a plot.

```
     DO YOU WANT TO PLOT THE TEMPERATURE VS. TIME
     IN HARVARD GRAPHICS? Y OR N  Y ⟨CR⟩
```

If you answer yes (Y) then you must type in a new file name for the HARVARD GRAPHICS temperature file.

```
THE TEMPERATURE DATA IS STORED IN FILE:  TFILE1

ENTER THE FILE TO STORE THE HARVARD GRAPHICS
TEMPERATURES USING UP TO 12 CHARACTERS
INCLUDING THE ENDING .DAT   HGTFILE1.DAT
```

The following will then appear on the next screen:

```
THE MODEL OUTPUT IS IN FILE:  OUTFILE
USE "PRINT" OR "TYPE " AFTER YOU EXIT THE PROGRAM TO SEE IT.

THE TEMPERATURES AT EACH NODE ARE IN FILE:  TFILE1
USE "PRINT" OR "TYPE " AFTER YOU EXIT THE PROGRAM TO SEE IT.

THE TEMPERATURES FOR THE HARVARD GRAPHICS PLOTS ARE IN FILE:
HGTFILE1.DAT    USE "PRINT" OR "TYPE" AFTER YOU EXIT THE PROGRAM
TO SEE IT.

THE SUMMARY PRINTOUT IS IN FILE: SUM1
USE "PRINT" OR "TYPE " AFTER YOU EXIT THE PROGRAM TO SEE IT.

        TYPE A <CR> TO CONTINUE. <CR>
```

The following question will appear next on the screen:

```
    DO YOU WANT TO CONTINUE? Y OR N
```

At this point choosing yes (Y) takes you back to the following screen:

```
        TYPE THE NUMBER OF THE FUNCTION BELOW THAT YOU
        WISH TO PERFORM.

            CHOOSE A FUNCTION NUMBER:
                1 - CHANGE SELECTED INITIAL VALUES
                2 - NO CHANGES--CONTINUE RUNNING THE PROGRAM
                3 - EXIT

            PLEASE ENTER THE FUNCTION NUMBER:
```

If you choose no (N) at the "DO YOU WANT TO CONTINUE?" you will see the following question:

```
        DO YOU WANT TO DO ANOTHER RUN? Y OR N
```

If you answer yes (Y) you will be taken back to the following screen to change any desired input parameters:

```
                    SKIN DIFFUSION DATA
                    INPUT PARAMETER LIST

TEMPI0 =  32.5000      DENS =   1.00000        Q1 =     .40000
BL =     .22000        AK =     .01000         JINC = 12
TEMPB =   4.50000      ABSORB =    .94000      BOIL =  100.15000

PL1 =    1.46000       PLN1 = 147.37000        DE1 =    50000.0
PL2 =    2.24000       PLN2 = 239.47000        DE2 =    80000.0
ETIME =  5.60000       ITIME =  80.00000       NXTRA = 7
BLOOD =   .00070

APL1 =    .78000       APLN1 = 285.52000       ADE1 =    93534.9
APL2 =    .60000       APLN2 = 117.43000       ADE2 =    39109.8

THE EXTRA NODES ARE:  25.0  50.0  75.0  100.0  125.0  150.0  175.0

          DO YOU WANT TO MAKE ANY CHANGES? Y OR N
```

If you answer no (N) to "DO YOU WANT TO DO ANOTHER RUN?", you will exit the BURNSIM program.

If you type the file SUM1 the following appears on the screen:

```
        MODEL NAME OR DESCRIPTION: TEST OF A. STOLL .4CAL 5.6SEC CASE

                    SKIN DIFFUSION DATA
                    INPUT PARAMETER LIST

    TEMPI0 =   32.50000      DENS =    1.00000       Q1 =     .40000
    BL =      .22000         AK =     .01000         JINC = 12
    TEMPB =    4.50000       ABSORB =     .94000     BOIL =  100.15000

    PL1 =     1.46000        PLN1 =  147.37000       DE1 =    50000.0
    PL2 =     2.24000        PLN2 =  239.47000       DE2 =    80000.0
    ETIME =    5.60000       ITIME =   80.00000      NXTRA =  7
    BLOOD =
    APL1 =     .78000        APLN1 =  285.52000      ADE1 =    93534.9
    APL2 =     .60000        APLN2 =  117.43000      ADE2 =    39109.8

     THE EXTRA NODES ARE:   25.0  50.0  75.0 100.0 125.0 150.0 175.0

         FLUX FILE I.D.:              .00   2

 FLUX(I)=
     1    .400    2    .400

 W=           .21973E+01
 W=           .12061E+00
 W=           .14088E-01

 D=          -.16000E+02
```

```
D=          .52983E+01
D=          .59915E+01

        W=1 LIES ABOVE NODE 2.  INTERCOLLATING VALUES OF D
        AND W COMPUTED FROM INTERPOLATED VALUES OF D AND
        TEMPERATURE.

W=          .10360E+01
W=          .86923E+00
W=          .73320E+00

D=          .46052E+01
D=          .48283E+01
D=          .50106E+01

W =         .21973E+01     AT DEPTH (IN MICRONS)=        .112535E-06
W =         .18217E+01     AT DEPTH (IN MICRONS)=        25.0000
W =         .14992E+01     AT DEPTH (IN MICRONS)=        50.0000
W =         .12423E+01     AT DEPTH (IN MICRONS)=        75.0000
W =         .10360E+01     AT DEPTH (IN MICRONS)=       100.000
W =         .86923E+00     AT DEPTH (IN MICRONS)=        125.000
W =         .73320E+00     AT DEPTH (IN MICRONS)=        150.000
W =         .62140E+00     AT DEPTH (IN MICRONS)=        175.000
W =         .12061E+00     AT DEPTH (IN MICRONS)=        200.000
W =         .14088E-01     AT DEPTH (IN MICRONS)=        400.000
W =         .47704E-02     AT DEPTH (IN MICRONS)=        600.000
W =         .21844E-02     AT DEPTH (IN MICRONS)=        800.000

MAXIMUM TEMPERATURE =   60.056

THRESHOLD DEPTH =            104.6

FINAL TIME =   14.04

TIME TO PAIN IS    1.59 SECONDS.
```

If you plot the data saved in TFILE1 and overlay Stoll's measured data, we get the following:

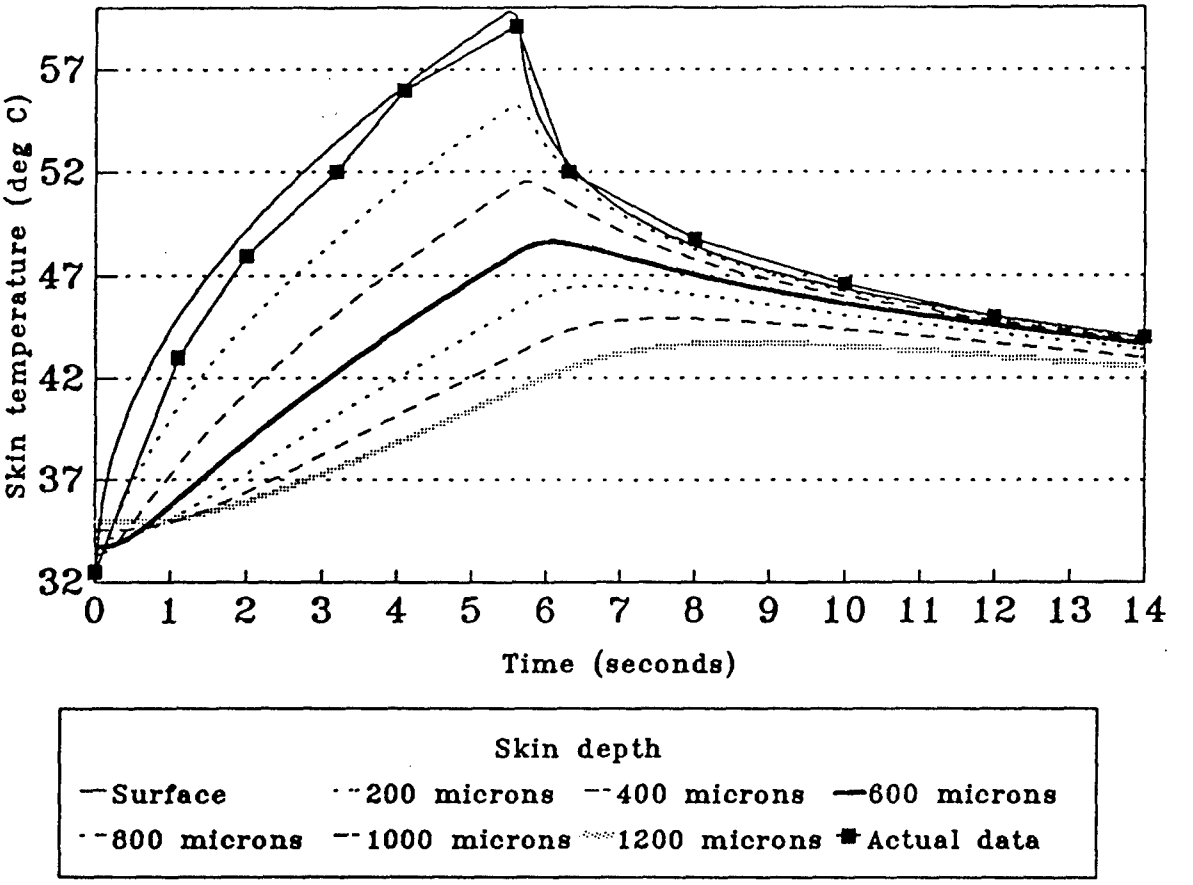

Figure 3. Skin temperatures at first six nodes calculated with Burnsim for Stoll's Data

Notice that there is reasonable fit between the computed temperature profiles and the recorded temperature. The predicted depth is 104.9 microns. Stoll observed a threshold blister, hence the damage should be between 80μm and 120μm.

Helpful hints

This section is devoted to explaining the inputs to the model and some hints about how to set up the model for special cases. The inputs are summarized in Table A-1.

There are nine special cases which have been found by previous users. First, for short exposures of less than 1 second, change the calculation interval (AK) from its normal value of .01 second to some value which is at least 100 times less than the duration. Thus, for an

exposure of 0.1 sec use AK = 0.001 second. Second, if the skin has been blackened, e.g., with india ink, use an absorptivity of about 0.92 to 0.94. Third, the default value of 0.613 for absorptivity assumes that 100 percent of the convective energy is absorbed, only 60 percent of the radiative energy is absorbed, and 5 percent of incident radiation is intercepted by hair. Thus, assuming

1) Q incident = 0.1 qi (convective) + 0.9 qi (radiative)
2) 5 percent radiative is not absorbed because of hair stubble,

then Q = 0.1 qi + 0.6(.9)(.95)qi = 0.613 qi

Fourth, use NXTRA 7 especially for mild exposures so that shallow burn depths are calculated more accurately. Fifth, a value of 0.0007 for Blood works best for shallow human burns.

Sixth, new values for DE1, DE2, PL1, PLN1, PL2, and PLN2 can be calculated if you wish to try rate constants published by other authors (see model derivation in Appendix A).

Seventh, it is possible to calculate new thermal properties based on humidity changes. Read the paper on thermal properties published in the journal Burns (Knox et al. 1986).

Eighth, the model currently assumes that ambient temperature is 23.9°C. Thus, during cool down the surface loses heat to a 23.9°C environment. This number can be changed only in the source code in the following line:

```
If (TIME.GE.ETIME)Q1 = -5.E-4*(t(1)-23.9)
```

Nine, for very severe exposures, where water boils in more than the first node, the thermal property recalculations routine causes an instability in the cool down phase. This can be seen if the data are plotted and can be avoided by setting the boil temperature to a much higher value. A permanent fix for this bug will appear in the next version of BURNSIM.

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Appendix A

ANALYTICAL MODEL

Several years ago Weaver and Stoll (1969) proposed an extension of Stoll's earlier model (Stoll and Greene, 1959) to heat fluxes higher than those used in obtaining the experimental data upon which the earlier model had been based. They also found that the effective conductivity changed during the exposure and subsequent cooldown period. Takata (1974), using preliminary data from USAARL's Thermal Project (the uncorrected version of the current data base), formulated a model which not only predicted threshold burns but deep burns and tissue water boiling as well. Building on the work of Henriques (1947), Stoll and Greene (1959), Weaver and Stoll (1969), Mehta and Wong (1973) and Takata (1974), an analytical model was formulated as follows:

For the thermal exposure of interest, skin is essentially opaque to thermal radiation and can be considered to transfer energy internally by conduction only, since exposure durations are no longer than the minimum response times reported for increased thermoregulatory system activity (1954). Consequently, thermal energy transfer in skin can be described by the heat conduction or Fourier equation be written as follows:

$$\rho\ Cp\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(K\frac{\partial T}{\partial x}\right)+q \qquad (1)$$

where,

ρ = density, gm/cm^3

Cp = heat capacity, cal/gm-°C

K = thermal conductivity, cal/cm-sec-°C

T = temperature, °C

x = distance, cm

q = energy source, for the first nodal volume, cal/cm^3-sec

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[1]Simplifying assumption base on the predominance of the radiate mode of heating. May be less valid with fabrics. In actuality a correction is made to q to account for convective heating, surface absorptivity, and attenuation of radiant heating by hair.

Since skin is considered to be opaque to radiant energy from a post crash fire, and since the source term is due only to radiant energy[1], equation (1) applies only to the surface of the skin. For all conditions in which x > 0, equation (1) reduces to the following:

$$\rho\ Cp\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(K\frac{\partial T}{\partial x}\right) \tag{2}$$

Solution of equation (1) and (2) requires two boundary conditions for x, preferably at x = 0 and x = L, and initial conditions at t = 0 for all positions 0 < x < L. If one assumes that there is no backward flux of thermal energy at x = 0 (all conduction is into the skin), then the energy flux at x = 0 is zero and, consequently, $\partial T/\partial x = 0$. Similarly, if the problem assumes that an adiabatic backwell condition prevails at x = L, the fatty tissue, then the net flux out of the system at x = L is 0, or $\partial T/\partial x = 0$. These two boundary conditions indicate that the system is closed and that all thermal energy added to the system, $0 \le x \le L$, is distributed within the system and cannot escape.

Initial conditions are established by specifying a uniform temperature for all locations, $0 \le x \le L$ at time t = 0.

Consequently, the system may be defined by the following mathematical model:

$$\rho\ Cp\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(K\frac{\partial T}{\partial x}\right)+q \qquad @\ x = 0 \ : surface \tag{3a}$$

$$\rho\ Cp\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(K\frac{\partial T}{\partial x}\right) \qquad @\ 0 \le x \le L \tag{3b}$$

T_x = CORE TEMPERATURE = TEMPI0 + TEMPB

$$T = T_o,\ 0 \le x \le L,\ t = 0 \qquad \textit{Initial Conditions} \tag{4}$$

$$\frac{\partial T}{\partial x} = 0,\ x = 0,\ 0 \le t \le x \qquad \textit{Boundary Conditions } 1 \tag{5}$$

$$\frac{\partial T}{\partial x} = 0,\ x = L,\ 0 \le t \le x \qquad \textit{Boundary Conditions } 2 \tag{6}$$

Solution of mathematical model (Reneau and O'Young, 1976, 1977, 1978)

An analytical solution to equation set (3) was not considered feasible due to the variable nature of q, Cp and K, so explicit differencing methods of numerical analysis were employed to solve the equations. Several investigators working with linear systems have found that the Crank- Nicholson six point implicit differencing method provided an excellent numerical solution (Crank and Nicholson, 1947). For the solution of equation set (3) of the mathematical model, it was decided to apply the Crank-Nicholson method to the second order partial derivatives and corresponding explicit methods to the first order partials.

The grid work in Figure A-1 is a representative of the differenced system from x = 0 to x = L (j's) and t = 0 to t = τ (i's).

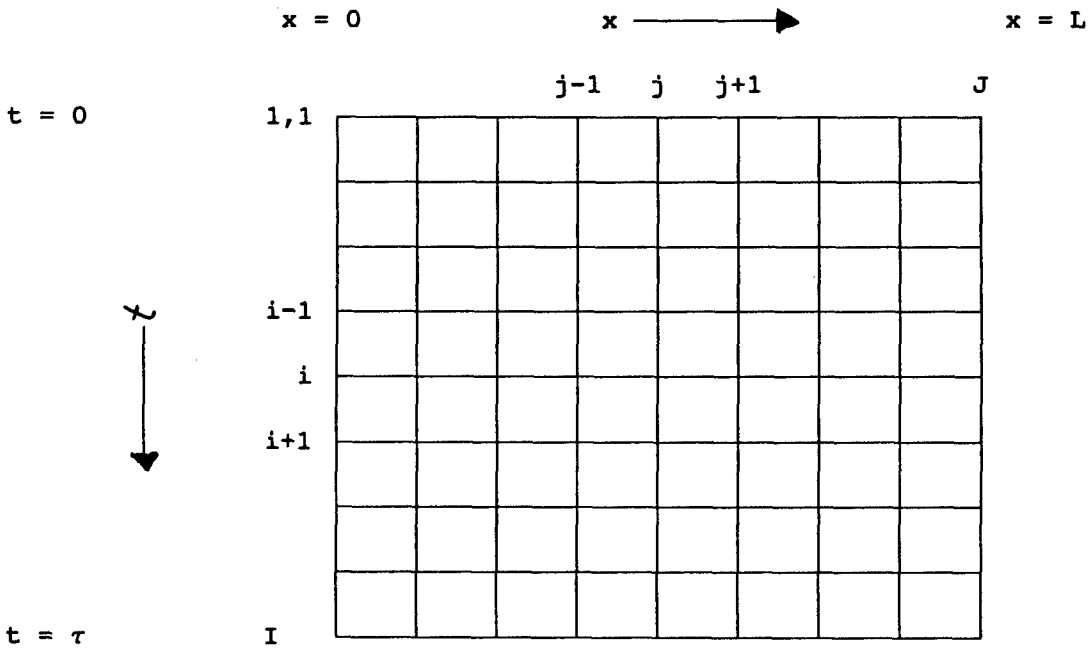

Figure A-1. Gridwork for numerical analysis

The Crank-Nicholson technique involves averaging the value of the dependent variable over the i and i + 1 row at a constant j position. The second order derivative is then evaluated at the (j, i + 1/2) position. A forward difference formulation is applied to the term to match the same position.

The above described implicit differencing method is noted for the characteristics of stability and convergence. Correct increment sizes yield reliable convergence. The model was implemented in FORTRAN IV using solution techniques of Thomas as described by Bruce et al. (1953).

This initial model was revised to allow energy flux across the surface, x = 0, during heating, convective heat loss at the skin surface during cooling and heat transfer into deep tissues including conduction into fat, convective cooling via the blood, tissue water boiling, a temperature gradient from surface to fat and a gradient of thermal properties based on measured tissue water. The model, BURNSIM, is a run interactively with the following variables changeable for each run:

Table A-1
Model parameters changeable interactively

INPUTS

TEMPI0	=	Initial surface temperature, °C; nominally 32.5 °C for man
DENS	=	Density of skin, 1.0 gm/cm^3
Q1	=	Incident heat flux either constant or as a file of fluxes, cal/cm^2-sec
BL	=	Skin thickness, 2200μm (The last 200μm is considered to be fat)
AK	=	Calculation interval, nominally .01 sec. For short exposures, the calculation interval must be at least one hundred times less than the exposure duration.
JINC	=	Number of nodes, nominally 12
TEMPB	=	Differences between TEMPI0 and backwall (fat/core) temperature, °C. Note: TEMPI0 + TEMPB = core temperature
Absorb	=	Absorptivity usually 0.613 assuming 10 percent convective, 90 percent radiative heating, and 5 percent of radiation intercepted by hair
Boil	=	Temperature when water boiling occurs, 100.15 °C
ETIME	=	Exposure time, seconds
ITIME	=	Maximum calculation time, usually 80-100 seconds
Nxtra	=	Number of extra nodes between the surface and node #2 at 200μm, initially set at seven, used for superficial burns Note: The seventh node must be at 175μm for an accurate time to pain prediction.
Blood	=	Factor to adjust amount of convective cooling by blood usually set at 0.001

DE1 & DE2 = $\Delta E/R$ from Arrehenius relationship for tissue temperatures from 44°C to 50°C, or over 50°C, respectively

PL1, PLN1, or PL2 and PLN2 => log P = logN + ylog10 = PL + PLN for tissue temperatures from 44°C to 50°C, or over 50°C, respectively

Damage Rate Constants: PL1, PLN1, PL2, PLN2, DE1, DE2 (for Nodes 2-12) APL1, APLN1, APL2, APLN2, ADE1, ADE2 (for Nodes 1 and Xtra Nodes)

Cp(J) = Heat capacity as a function of depth, (J)

BK(J) = Thermal conductivity as a function of depth, (J)

PCWATER = Percent water at a skin depth of 10μm at 60 percent relative humidity

WATER(J) = Percent water at each node based on 60 percent relative humidity

OUTPUTS

Flux (I) - tabulated heat flux as a function of time

DAMAGE, W, at each depth (Node)

Maximum temperature

Threshold depth in μm (microns)

Final time - total calculation time

Time to pain

File of calculated temperatures for later plotting by HARVARD GRAPHICS

File summarizing simulation

File of temperature as printed each second on the terminal

From the relationship for first order kinetics assumed to apply in damaging tissue protein we have:

$$damage\ rate = \frac{d\Omega}{dt} = Pe^{-\Delta E/RT};$$

$$\text{total damage} = \int_0^{\text{ETIME}} \frac{d\Omega}{dt} + \int_{\text{ETIME}}^{\text{ITIME}} \frac{d\Omega}{dt} \qquad (8)$$

if $P = N \times 10^y$ and $\Delta E/R = DE$

then:

$$\ln\frac{dW}{dt} = lnN + yln10 - \frac{\Delta E}{R} \cdot \frac{1}{T} = PL + PLN - DE \cdot \frac{1}{(T+273)} \qquad (9)$$

Thus for damage calculations the following constants are entered:

PL_1 (44°C - 50°C) = 1.46 PL_2 (50°C - 100°C) = 2.24

PLN_1 (44°C - 50°C) = 147.37 PLN_2 (50°C - 100°C) = 239.47

DE_1 (44°C - 50°C) = 50,000 DE_2 (50°C - 100°C) = 80,000

The program outputs $d\Omega/dt$, for each node at each time step, total is damage for each node and a threshold depth, where $\Omega = 1$. This depth, found using inverse interpolation on two or three Ωs nearest 1 using either y or log(y).

Since the first presentations (Knox, Wachtel, and Knapp, 1978a, 1978c) BURNSIM has under gone further development.

Thermal properties of skin

Measurements of the water content of pig skin as a function of thickness were made on split thickness skin samples from several pigs.

Give a table of measured values of water content as a function of skin thickness, a least-square cubic polynomial was fit to the data and water content as a function of depth was computed from the formula:

$$W(T-d) = \frac{T}{d}(W_T - W_{T-d}) + W_{T-d} \qquad (10)$$

where T is the total thickness of a slab, W_T is the fraction of water computed from the cubic equation, d is the thickness of a thin slab at a depth T-d, and W_{T-d} is the fraction of water above the thin slab.

Thermal properties of the tissue were computed from the equations (Cooper and Trezek, 1971):

$$1)\ density:\ \gamma = \left[\frac{W_w}{\gamma_w} + \frac{W_f}{\gamma_f} + \frac{W_p}{\gamma_p}\right]^{-1} \qquad (11)$$

2) *heat capacity*: $Cp = W_w Cp_w + W_f Cp_f + W_p Cp_p$ (12)

3) *thermal conductivity*: $K = \gamma \left[\frac{k_w W_w}{\gamma_w} + \frac{k_f W_f}{\gamma_f} + \frac{k_p W_p}{\gamma_p} \right]$ (13)

where the subscripts w, f, and p refer to water, fat, and protein, respectively. W_n is the mass fraction, γ_n the density, Cp_n the heat capacity, and k_n the thermal conductivity of the respective components. Values of the various terms used were:

$\gamma_w = 1$ gm/cm^3 $\quad Cp_w = 1$ cal/gm-°C $\quad k_w = 1.5X10^{-3}$ cal/cm-sec-°C

$\gamma_f = 0.815$ gm/cm^3 $\quad Cp_f = 0.55$ cal/gm-°C $\quad k_f = 4.5X10^{-4}$ cal/cm-sec-°C

$\gamma_p = 1.54$ gm/cm^3 $\quad Cp_p = 0.26$ cal/gm-°C $\quad k_p = 4.3X10^{-4}$ cal/cm-sec-°C

Fat and protein were assumed to be present in equal amounts so that:

$$W_f = W_p = (1-W_w)/2, \quad (14)$$

and the resultant equations were:

$$\gamma = (6.18277X10^{-2}\ W_w + .938172)^{-1} \quad (15)$$

$$K = \gamma(1.08432X10^{-3}\ W_w + 4.15684X10^{-4}) \quad (16)$$

$$Cp = .595\ W_w + .405 \quad (17)$$

Using the equations above, the profile of thermal properties was calculated for skin depths of from 80 to 2000μm. A linear extrapolation of tissue water content from a depth of 80μm to the skin surface was made using a stratum corneum water content calculated from Rushmer et al. (1966) and the ambient percent humidity during the experimental phase of the project. This calculated water profile was used to complete the calculation of thermal properties profile from 80μm to the skin surface. The thermal properties of the skin at 2200μm were assumed to be those of fat. These new thermal properties replaced those chosen by Morse et al. (1973) and used during previously reported simulations (Knox, Wachtel, and Knapp, 1978a, 1978c). See the paper entitled "Thermal properties calculated from measured water content as a function of depth in porcine skin" (Knox et al., 1986).

Intraskin temperatures

In earlier simulations (Knox et al, 1978a, 1978c) it became apparent that unless the temperature calculations reasonably represented what actually occurred in the skin, adjustment of the values for PL, PLN and DE in the damage equation to match a few data points would not be likely to result in a model which works well for all cases. Fortunately

11 intraskin temperature profiles were recorded on FM magnetic tape. These voltage records were digitized and converted to tables of temperatures at 100 samples per second. Figure A-2 presents the one page summary report from a simulation of the exposure of Pig 294RF to a 3.47 cal /cm^2-sec fire for 3.02 seconds. Note that boiling occurred (confirmed by blister formation, Figure A-3) and that the surface reached a maximum of 128.724°C. Predicted threshold depth was 1520μm. Three observed temperature profiles are overlayed on the calculated temperature profiles (for nodal depths of 0, 200, 400....2200μm) in Figures A-4, A-5, and A-6. The oscillations in the observed temperature profile are most probably due to a "hunting" in the autoregulation of tissue perfusion by blood. The frequency, for example, is similar to that seen in studies of microcirculation.

```
MODEL NAME OR DESCRIPTION: PIG 294RF ABS 0.613

                    SKIN DIFFUSION DATA
                    INPUT PARAMETER LIST

TEMPIO=   34.9700        DENS=   1.00000        Q1=   3.47000
BL=    .220000           AK=    .100000E-01     JINC=    12
TEMPB=  3.3600           ABSORB=    .613000     BOIL=   100.150

APL1=    .780000         APLN1=   285.520       ADE1=   93534.9
APL2=    .600000         APLN2=   117.430       ADE2=   39109.8

PL1=       1.46          PLN1=    147.37        DE1=  50000.00
PL2=       2.24          PLN2=    239.47        DE2=  80000.00
ETIME=     3.02          ITIME=     80.00       NXTRA=    8
BLOOD=     .0010

 EXTRA NODES:   22.2  44.4  66.7  88.9 111.1 133.3 155.6 177.8

 FLUX FILE I.D.:              .00   2

  FLUX(I)=
     1   3.470    2   3.470

 W=           .39950E+01
 W=           .40733E+00
 W=           .45290E-01

 D=           .72442E+01
 D=           .73778E+01
 D=           .74955E+01

 W =           .19755E+19     AT DEPTH (IN MICRONS)=          .112535E-06
 W =           .82482E+12     AT DEPTH (IN MICRONS)=          200.000
 W =           .26532E+09     AT DEPTH (IN MICRONS)=          400.000
 W =           .57713E+06     AT DEPTH (IN MICRONS)=          600.000
 W =           .84775E+04     AT DEPTH (IN MICRONS)=          800.000
 W =           .44473E+03     AT DEPTH (IN MICRONS)=          1000.00
 W =           .39319E+02     AT DEPTH (IN MICRONS)=          1200.00
 W =           .39950E+01     AT DEPTH (IN MICRONS)=          1400.00
 W =           .40733E+00     AT DEPTH (IN MICRONS)=          1600.00
 W =           .45290E-01     AT DEPTH (IN MICRONS)=          1800.00
 W =           .89902E-02     AT DEPTH (IN MICRONS)=          2000.00
 W =           .00000E+00     AT DEPTH (IN MICRONS)=          2200.00

 MAXIMUM TEMPERATURE =  128.724

 THRESHOLD DEPTH =            1528.

 FINAL TIME =   80.00
```

Figure A-2. Summary report for simulation of Pig 294RF to a 3.47 cal/cm²-sec fire for 3.02 seconds.

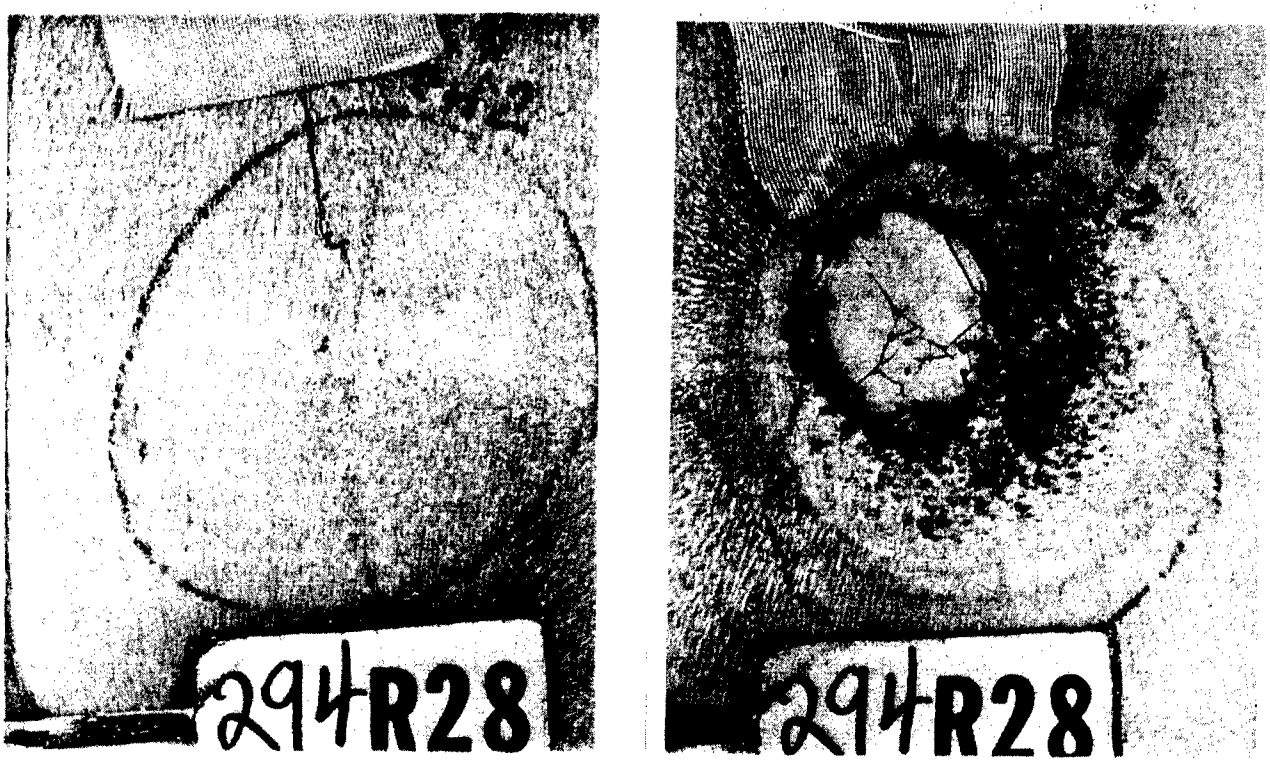

Figure A-3. Intraskin thermocouple (0.003", "located superficially") shown prior to burn (left) and subsequent to exposure to 3.47 cal•cm^{-2}•sec^{-1} for 3.02 seconds (right).

Gross grade = 13 New micro grade = 8
Threshold depth = 1465μm

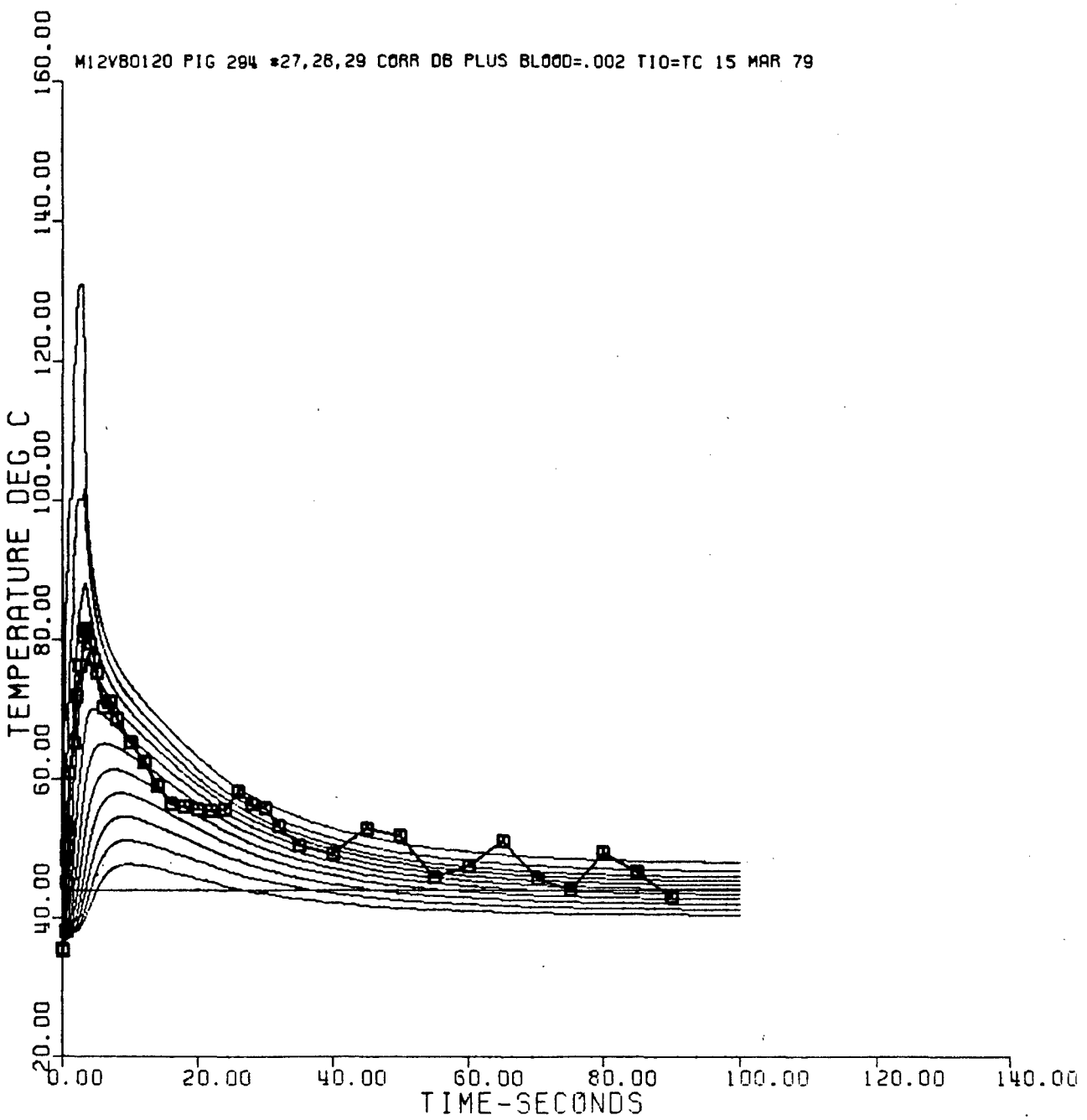

Figure A-4. Predicted skin temperature at each node (solid lines) and measured intraskin temperature in pig 284 location #27 when exposed to 3.47 cal.cm^{-2}.sec^{-1} for 3.02 seconds

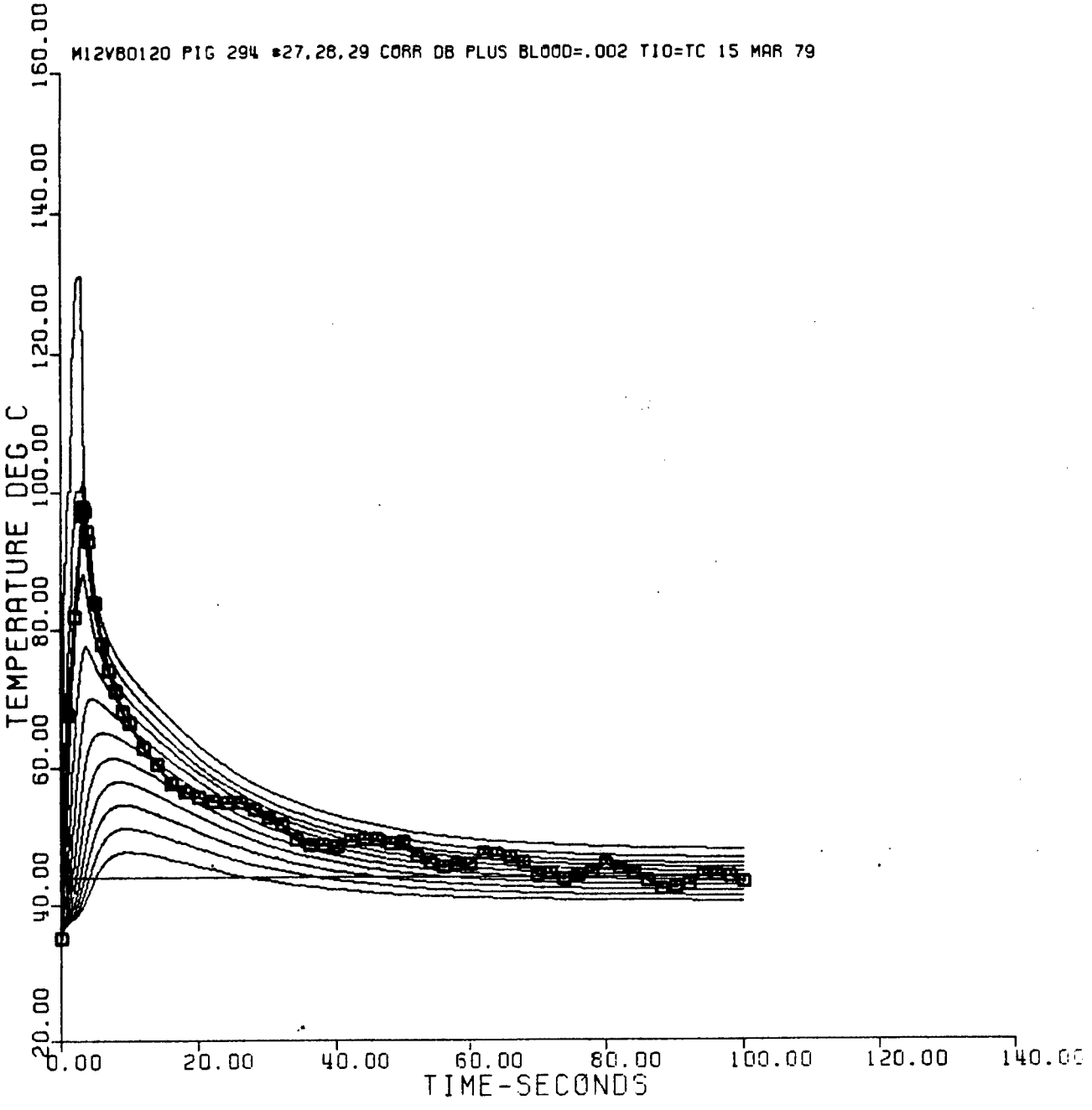

Figure A-5. Predicated skin temperature at each node (solid lines) and measured intraskin temperature in pig 284 location #28 when exposed to 3.47 cal·cm^{-2}·sec^{-1} for 3.02 seconds

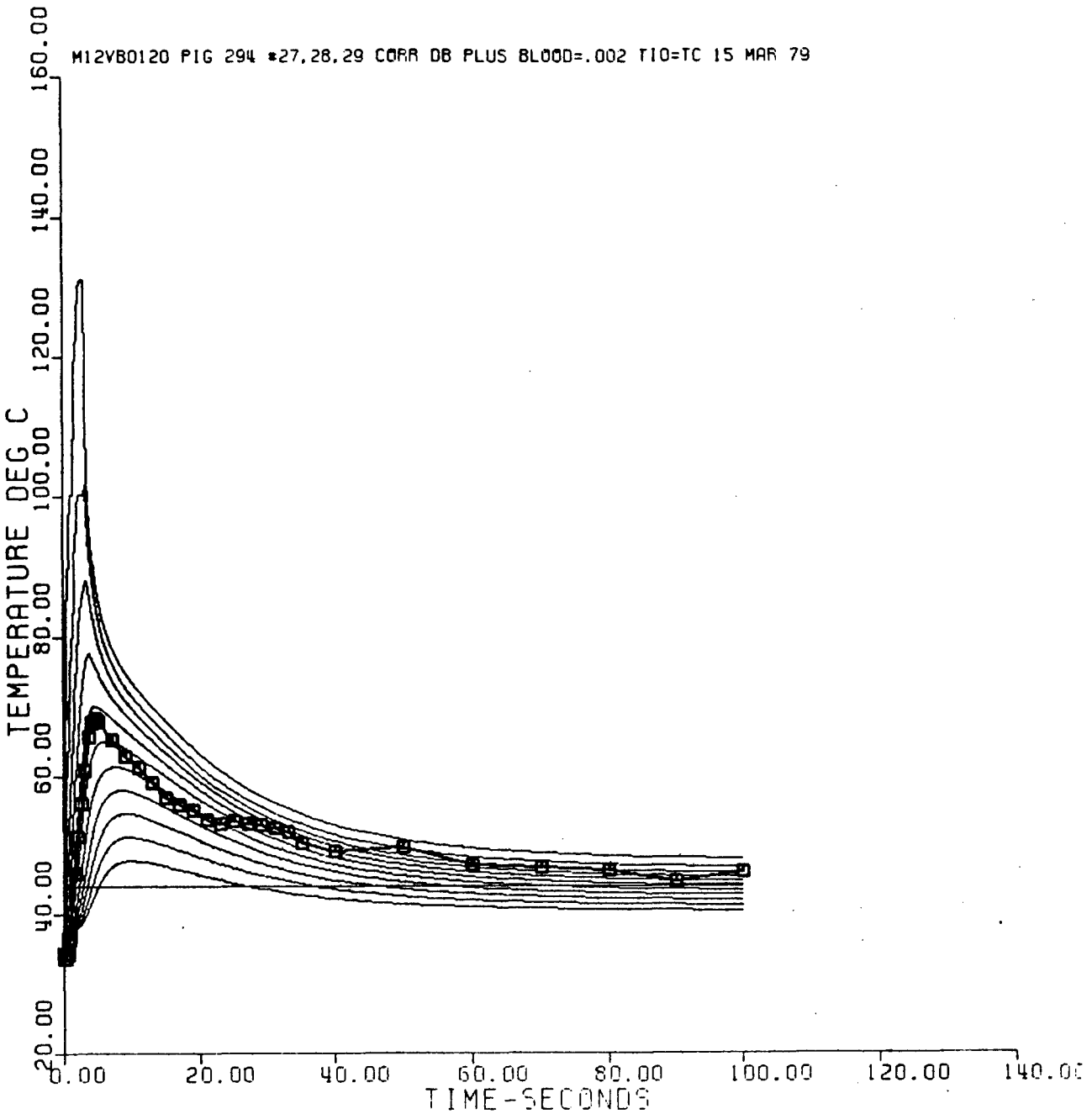

Figure A-6. Predicated skin temperature at each node (solid lines) and measured intraskin temperature in pig 284 location #29 when exposed to 3.47 $cal \cdot cm^{-2} \cdot sec^{-1}$ for 3.02 seconds

APPENDIX B

```
C       Last Edited March 5, 1992
C       ******************** 12-POINT BURN PREDICTION MODEL***************

C     PROGRAM BURNSIM          ! BURN PREDICTION MODEL WITH WATER BOILING
C                              ! AND USE OF EITHER CONSTANT OR TABULATED FLUX
C                              ! AND VARIABLE COOLING BY BLOOD FROM NODES 2
C                              ! AND 3 BEGINNING AT .01 SEC AND LINEARLY
C                              ! INCREASING TO 20 SEC AND THEN REMAINING
C                              ! CONSTANT......

C                              ! CHANGED TO DO INTEGRATION OF DAMAGE W & XW
C                              ! WITHIN PROGRAM AND NOT OUT TO DISK AND BACK

C                              ! CHANGED TO INCORPORATE THE CHANGES IN MODEL
C                              ! 7 NAMELY DIFFERENT RATE CONSTANTS ETC FOR
C                              ! SUPERFICIAL NODES AND VARIABLE AK IN BLUD

C       THIS MODEL WAS DEVELOPED UNDER CONTRACT FOR THE U.S. ARMY
C       MEDICAL RESEARCH AND DEVELOPMENT COMMAND, AND THE U.S. ARMY
C       AEROMEDICAL RESEARCH LABORATORY, FORT RUCKER AL. 36362,
C       STANLEY C. KNAPP, COL, MC, COMMANDING, BY FRANCIS S. KNOX, III,
C       PH.D. WITH THE ASSISTANCE OF DANIEL D. RENEAU, PH.D., NELSON
C       O'YOUNG, AND CHET ELLIS, M.S.

C       ADDITIONAL DEVELOPMENT CONDUCTED UNDER ILIR FUNDING AT USAARL
C       AND ON OWN TIME BY FRANCIS S. KNOX, III, PH.D.

C       QUESTIONS AND COMMENTS SHOULD BE ADDRESSED TO:

C               FRANCIS S. KNOX, III, PH.D
C               CHIEF, ESCAPE AND IMPACT PROTECTION BRANCH
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C               COM. 513-255-3931  AV 785-3931

C      This copy current working copy of Dr. Knox. Other copies
C      are not to be further distributed without permission from
C      Dr. Knox.
C.....
      INCLUDE 'FGRAPH.FI'
      INCLUDE 'FGRAPH.FD'
      REAL*4 ITIME,NOFIL,TP,SUM(13),DW(13)
      INTEGER CHANGE,PTS,AGAIN,PROCED
      INTEGER*4 DUMMY4
      INTEGER*2 DUMMY2
      DIMENSION T(12),F(12),G(12),H(12),W(12),Z(12),SV(12),U(12)
      DIMENSION CP(12,2),BK(12,2),D(12),DSCRPT(20)
      DIMENSION ID(4),FLUX(600),Q(12)
```

```
      DIMENSION XTIME(12),ZTIME(12),IFLAG(12),JFLAG(12)
      DIMENSION WATER(12,2),ROCON(2),THCON(2),CPCON(2)
      DIMENSION XW(8),XTRA(8),XTRALG(8),XTMP(8),XDW(8),XSUM(8)
      CHARACTER RESP*1,FILNAM*8,SUMFILE*8,PROFILE*8,TFILE*8
      EQUIVALENCE (NOFIL,IBLNK)
        DATA NOFIL/'    '/
        DATA MAXDIM/12/,D2/200./
        DATA THCON/1.084316E-3,4.1568401E-4/
        DATA ROCON/6.1827743E-2,0.93817226/
        DATA CPCON/0.595,0.405/

C       LOGICAL UNIT 1 INPUT  : 'REN12.DAT'; INITIAL VALUES OF PARAMETERS
C       LOGICAL UNIT 1 SCRATCH:  VALUES OF XW (IF COMPUTED)
C       LOGICAL UNIT 2 SCRATCH:  VALUES OF W (COMPUTED)
C       LOGICAL UNIT 3 OUTPUT :  PROFILE; TEMPERATURE PROFILES
C       LOGICAL UNIT 4 INPUT  :  FILNAM; NAME OF FLUX FILE
C       LOGICAL UNIT 4 OUTPUT :  TFILE; DATA FOR PLOTTING TEMPERATURE
C                                PROFILES
C       LOGICAL UNIT 7 OUTPUT :  SUMMARY PRINTOUT

C*******Introduction to BURNSIM
        CALL COLORS
        DUMMY4=SETBKCOLOR( $BLUE )
        CALL WELCOME(PROFILE)
C*******Read REN12.DAT input file
        CALL READDATA(TEMPI0,DENS,Q0,BL,AK,BOIL,ABSORB,JINC,TEMPB,
     +  ITIME,ETIME,PCWATR,BLOOD,CP,BK,PL2,PLN2,PL1,PLN1,DE2,DE1,
     +  APL1,APLN1,APL2,APLN2,ADE1,ADE2,WATER)
        OPEN(UNIT=1,FORM='UNFORMATTED',STATUS='SCRATCH')
        OPEN(UNIT=2,FORM='UNFORMATTED',STATUS='SCRATCH')
        OPEN(UNIT=3,FILE=PROFILE,FORM='FORMATTED',STATUS='UNKNOWN')
        FLUX(1) = Q0
        FLUX(2) = Q0
        NFLX = 2
        FILNAM = NOFIL
        PPL1 = PL1
        PPLN1 = PLN1
        DDE1 = DE1
        APPL1 = APL1
        APPLN1 = APLN1
        ADDE1 = ADE1
        NXTRA = 0
        NXTRA0 = NXTRA
C*******Display input values on screen
        CALL SHOWVALUE(TEMPI0,DENS,FLUX,BL,AK,JINC,TEMPB,
     + ABSORB,BOIL,PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,
     + BLOOD,APL1,APLN1,ADE1,APL2,APLN2,ADE2,K,XTRA)
        DO WHILE (AGAIN .EQ. 0)
         CALL PROCEED(RESP,PROCED,AGAIN)
         IF(PROCED.EQ.0) THEN
          PTS=1
          TIME=0.
```

```
          CHANGE=0
          MN=0
          CALL clearscreen( $GCLEARSCREEN )
          WRITE(*,10)
10      FORMAT(//,15X,'TYPE THE NUMBER OF THE FUNCTION BELOW THAT YOU',/
     + ,15X,'WISH TO PERFORM.',////,20X,'CHOOSE A FUNCTION NUMBER: ',/,
     + 25X,'1 - CHANGE SELECTED INITIAL VALUES',/,25X,'2 - NO CHANGES',
     + '--CONTINUE RUNNING THE PROGRAM',/,25X,'3 - EXIT',//,20X,'PLEASE'
     + ' ENTER THE FUNCTION NUMBER: '$)
          READ(*,20)IANSR
20      FORMAT(I2)
          CALL clearscreen( $GCLEARSCREEN )
          IF(IANSR.EQ.1) THEN
           DOWHILE(CHANGE.EQ.0)
            CALL SHOWVALUE(TEMPI0,DENS,FLUX,BL,AK,JINC,TEMPB,
     + ABSORB,BOIL,PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,
     + BLOOD,APL1,APLN1,ADE1,APL2,APLN2,ADE2,K,XTRA)
           WRITE(*,30)
30      FORMAT(///,15X,'DO YOU WANT TO MAKE ANY CHANGES? TYPE Y/N '$)
           READ(*,40)RESP
40      FORMAT(A1)
          IF(RESP.EQ.'Y'.OR.RESP.EQ.'y') THEN
           CALL CLEARSCREEN( $GCLEARSCREEN )
           WRITE(*,50)
50      FORMAT(/T5,'PICK A NUMBER',//T10,'1=TEMPI0',T30,'8=ETIME',//
     + T10,'2=DENS',T30,'9=PL1',/T10,'3=Q1',T30,'10=PLN1',//
     + T10,'4=BL',T30,'11=PL2',/T10,'5=AK',T30,'12=PLN2',//
     + T10,'6=JINC',T30,'13=DE1',/T10,'7=TEMPB',T30,'14=DE2',//
     + T10,'15=ITIME',T30,'16=ABSORBTIVITY'//
     + T10,'17=BOIL',T30,'18=EXTRA NODES'//
     + T10,'19=BLOOD',T30,'20=APL1'//
     + T10,'21=APLN1',T30,'22=APL2'//
     + T10,'23=APLN2',T30,'24=ADE1',T55,'25=ADE2',/,9X,$)
          READ(*,20)INUM
          IF(INUM.EQ.1) THEN
           WRITE(*,60)TEMPI0
60      FORMAT(///,9X,'THE VALUE FOR TEMPI0 IS: ',F10.5,' INPUT NEW VALU'
     + 'E: '$)
           READ(*,70)TEMPI0
70     FORMAT(G10.5)
          ELSEIF(INUM.EQ.2) THEN
           WRITE(*,80)DENS
80      FORMAT(///,9X,'THE VALUE FOR DENS IS: ',F10.5,' INPUT NEW VALUE: '
     + $)
           READ(*,70)DENS
          ELSEIF(INUM.EQ.3) THEN
           WRITE(*,90)
90      FORMAT(///,9X,'ENTER THE FLUX FILE NAME (TYPE A <CR> IF NO FILE '
     + ,/,9X,'IS TO BE USED): '$)
           READ(*,100)FILNAM
100     FORMAT(A8)
C*******Read in flux file
```

```
            IF (FILNAM.NE.NOFIL) THEN
             WRITE(*,110)
110    FORMAT(/,9X,'ENTER FLUX ID (UP TO 8 CHARACTERS): '$)
             READ(*,120)
120    FORMAT(4A2)
             WRITE(*,130)
130    FORMAT(/,9X,'ENTER THE NUMBER OF POINTS IN FLUX FILE:  '$)
             READ(*,*) NFLX
              DO WHILE (NFLX .GT. 600)
               WRITE(*,140)
140    FORMAT(/,9X,'THE FLUX FILE MUST CONTAIN NO MORE THAN 600 DATA'
     +  ,/,9X,'POINTS.  REENTER A NUMBER LESS THAN OR EQUAL TO 600. '$)
               READ(*,*) NFLX
              END DO
              WRITE(*,150)
150    FORMAT(/,9X,'ENTER THE SAMPLE INTERVAL IN SECONDS: '$)
              READ(*,*)TDELT
              OPEN(UNIT=4,FILE=FILNAM,FORM='FORMATTED',STATUS=
     + 'OLD')
              READ(4,*) (FLUX(I),I=1,NFLX)
              CLOSE (4)
               IF(NFLX.LE.0) STOP 'ERROR----TOO FEW FLUX POINTS.'
              WRITE(*,430)ID,TDELT,NFLX
             ELSE
              WRITE(*,160)FLUX(1)
160    FORMAT(//,9X,'CONSTANT Q-VALUE = ',F10.5,'  INPUT NEW VALUE: '
     + $)
              READ(*,70)FLUX(1)
              FLUX(2)=FLUX(1)
              NFLX = 2
              DO I=1,4
               ID(I) = IBLNK
              END DO
             END IF
            ELSEIF(INUM.EQ.4) THEN
             WRITE(*,170)BL
170    FORMAT(//,9X,'THE VALUE FOR BL IS: ',F10.5,'  INPUT NEW VALUE: '
     + $)
             READ(*,70)BL
            ELSEIF(INUM.EQ.5) THEN
             WRITE(*,180)AK
180    FORMAT(//,9X,'THE VALUE FOR AK IS: ',F10.5,'  INPUT NEW VALUE: '
     + $)
             READ(*,70)AK
            ELSEIF(INUM.EQ.6) THEN
             WRITE(*,190)JINC
190    FORMAT(//,9X,'THE VALUE FOR JINC IS: ',I30,'  INPUT NEW VALUE: '
     + $)
             READ(*,20)JINC
             IF (JINC.GT.MAXDIM) JINC=MAXDIM
            ELSEIF(INUM.EQ.7) THEN
           WRITE(*,200)TEMPB
```

```
200    FORMAT (//,9X,'THE VALUE FOR TEMPB IS: ',F10.5,'  INPUT NEW VA'
     + 'LUE: '$)
            READ(*,70)TEMPB
           ELSEIF(INUM.EQ.8) THEN
            WRITE(*,210)ETIME
210    FORMAT(//,9X,'THE VALUE FOR ETIME IS: ',F10.5,'  INPUT NEW VALU'
     + 'E: '$)
            READ(*,70)ETIME
           ELSEIF(INUM.EQ.9) THEN
            WRITE(*,220)PL1
220    FORMAT(//,9X,'THE VALUE FOR PL1 IS: ',F10.5,'  INPUT NEW VALUE'
     + ': '$)
            READ(*,70)PL1
            PPL1=PL1
           ELSEIF(INUM.EQ.10) THEN
            WRITE(*,230)PLN1
230    FORMAT(//,9X,'THE VALUE FOR PLN1 IS: ',F10.5,'  INPUT NEW VALU'
     + 'E: '$)
            READ(*,70)PLN1
            PPLN1=PLN1
           ELSEIF(INUM.EQ.11) THEN
            WRITE(*,240)PL2
240    FORMAT(//,9X,'THE VALUE FOR PL2 IS: ',F10.5,'  INPUT NEW VALUE'
     + ': '$)
            READ(*,70)PL2
           ELSEIF(INUM.EQ.12) THEN
            WRITE(*,250)PLN2
250    FORMAT(//,9X,'THE VALUE FOR PLN2 IS: ',F10.5,'  INPUT NEW VALUE'
     + ': '$)
            READ(*,70)PLN2
           ELSEIF(INUM.EQ.13) THEN
            WRITE(*,260)DE1
260    FORMAT(//,9X,'THE VALUE FOR DE1 IS: ',F10.1,'  INPUT NEW VALUE'
     + ': '$)
            READ(*,70)DE1
            DDE1=DE1
           ELSEIF(INUM.EQ.14) THEN
            WRITE(*,270)DE2
270    FORMAT(//,9X,'THE VALUE FOR DE2 IS: ',F10.1,'  INPUT NEW VALUE'
     + ': '$)
            READ(*,70)DE2
           ELSEIF(INUM.EQ.15) THEN
            WRITE(*,280)ITIME
280    FORMAT(//,9X,'THE VALUE FOR ITIME IS: ',F10.5,'  INPUT NEW VALU'
     + 'E: '$)
            READ(*,70)ITIME
           ELSEIF(INUM.EQ.16) THEN
            WRITE(*,290)ABSORB
290    FORMAT(//,9X,'THE VALUE FOR ABSORB IS: ',F10.5,'  INPUT NEW VAL'
     + 'UE: '$)
            READ(*,70)ABSORB
           ELSEIF(INUM.EQ.17) THEN
```

```
            WRITE(*,300)BOIL
300    FORMAT(//,9X,'THE VALUE FOR BOIL IS: ',F10.5,'  INPUT NEW VALUE'
     + ': '$)
            READ(*,70)BOIL
           ELSEIF(INUM.EQ.18) THEN
            NXTRA0 = NXTRA
            WRITE(*,310)NXTRA
310    FORMAT(//,9X,'THE NUMBER OF EXTRA NODES IS: ',I4,'  INPUT NEW'
     + ' VALUE: '$)
            READ(*,20)NXTRA
            IF (NXTRA.NE.0) THEN
             IF (NXTRA.GT.8) NXTRA=8
             IF (NXTRA0.NE.0) WRITE(*,320) (XTRA(I),I=1,NXTRA0)
320    FORMAT(/,9X,'CURRENT EXTRA NODES: ',8F6.1)
             WRITE(*,330)
330    FORMAT(//,9X,'ENTER NEW VALUES SEPARATED BY COMMAS, OR A <CR> '
     +  ,/,9X,'IF THE PROGRAM IS TO CALCULATE VALUES. '$)
            READ(*,340)XTRA
340    FORMAT(8G6.1)
            IF (XTRA(1).LE.0) THEN
C*******Numerator in next statement is specific for n-point model
             DXTRA = D2/(NXTRA+1)
             DO I=1,NXTRA
              XTRA(I)  = DXTRA*I
             END DO
            END IF
            DO I=1,NXTRA
             XTRALG(I) = ALOG(XTRA(I))
            END DO
           END IF
           NXTRA0 = NXTRA
          ELSEIF(INUM.EQ.19) THEN
           WRITE(*,350)BLOOD
350    FORMAT(//,9X,'THE VALUE FOR BLOOD IS: ',F10.5,'  INPUT NEW VALU'
     + 'E: '$)
            READ(*,70)BLOOD
          ELSEIF(INUM.EQ.20) THEN
           WRITE(*,360)APL1
360    FORMAT(//,9X,'THE VALUE FOR APL1 IS: ',F10.5,'  INPUT NEW VALUE'
     + ': '$)
            READ(*,70)APL1
          ELSEIF(INUM.EQ.21) THEN
           WRITE(*,370)APLN1
370    FORMAT(//,9X,'THE VALUE FOR APLN1 IS: ',F10.5,'  INPUT NEW VALU'
     + 'E: '$)
            READ(*,70)APLN1
          ELSEIF(INUM.EQ.22) THEN
           WRITE(*,380)APL2
380    FORMAT(//,9X,'THE VALUE FOR APL2 IS: ',F10.5,'  INPUT NEW VALUE'
     + ': '$)
            READ(*,70)APL2
          ELSEIF(INUM.EQ.23) THEN
```

```
              WRITE(*,390)APLN2
390     FORMAT(///,9X,'THE VALUE FOR APLN2 IS: ',F10.5,'  INPUT NEW VALU'
     + 'E: '$)
              READ(*,70)APLN2
             ELSEIF(INUM.EQ.24) THEN
              WRITE(*,400)ADE1
400     FORMAT(///,9X,'THE VALUE FOR ADE1 IS: ',F10.1,'  INPUT NEW VALUE'
     + ': '$)
              READ(*,70)ADE1
             ELSEIF(INUM.EQ.25) THEN
              WRITE(*,410)ADE2
410     FORMAT(///,9X,'THE VALUE FOR ADE2 IS: ',F10.1,'  INPUT NEW VALUE'
     + ': '$)
              READ(*,70)ADE2
             ELSE
              CHANGE=1
             ENDIF
            ELSE
             CHANGE=1
            END IF
           END DO
           REWIND 1
          ELSEIF(IANSR.EQ.2) THEN
           CALL CLEARSCREEN( $GCLEARSCREEN )
           CALL DESCRIPT(DSCRPT,SUMFILE,TFILE)
           TP=999.
           AJ=JINC
           Q1 = FLUX(1)
           H1=BL/(AJ-1.0)
C*******Initialize depth nodes D(J)
           D(1) = -16.
           DO I=2,JINC
            D(I) = H1*(I-1)*1.E4
            D(I) = ALOG(D(I))
           END DO
            DTJ = TEMPB/(JINC-1)
            DO J=1,JINC
             WATER(J,1) = WATER(J,2)
             CP(J,1) = CP(J,2)
             BK(J,1) = BK(J,2)
             XTIME(J) =0.
             ZTIME(J) =0.
             IFLAG(J) =0.
             JFLAG(J) =0.
             T(J) = DTJ*(J-1)+TEMPI0
            END DO
             WRITE(4,420)TIME,T(1),T(2),T(3),T(4),T(5),T(6),T(7),T(8)
     + ,T(9),T(10),T(11),T(12)
420     FORMAT(13(F9.5,2X))
             K=1
             CALL SHOWVALUE(TEMPI0,DENS,FLUX,BL,AK,JINC,TEMPB,ABSORB,
     + BOIL,PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,BLOOD,APL1,
```

```
     + APLN1,ADE1,APL2,APLN2,ADE2,K,XTRA)
               WRITE(3,430)ID,TDELT,NFLX,(I,FLUX(I),I=1,NFLX)
               WRITE(7,430)ID,TDELT,NFLX,(I,FLUX(I),I=1,NFLX)
430      FORMAT(/,9X,'FLUX FILE I.D.: ',4A2,F7.2,I4://' FLUX(I)='
     + /(' ',10(I5,F8.3)))
               JJJJ=0
               F(1)=-BK(2,1)/(2.0*H1*H1)-BK(1,1)/(2.0*H1*H1)
               G(1) = (BK(1,1)+BK(2,1))/(2.0*H1*H1)+DENS*CP(1,1)/AK
               H(1)=0.0
               ITTR = 0
               IFLX = 1
               EITIM1 = ITIME+1.
               IF (FILNAM.EQ.NOFIL) TDELT=AK
               FFDG = TDELT/AK
               KFDG = FFDG+.0001
               TMPMAX = 0.
               QCONST = ABSORB*60.892
               BLUD = 0.
               M = -1
               TIME = 0.
               ITFLG = 0
               CALL SUB12(TIME,T,XTIME,JINC,BLUD,CP,BK,NXTRA,XTMP,M,EM)
               DOWHILE(TIME.LT.ITIME.AND.ITFLG.EQ.0.OR.TIME.LT.ETIME)
C*******The next program statement automatically chooses the proper
C        interval in the flux table for the computation of QT and Q1 for
C        either constant or variable flux.
C             KFDG (=FFDG) = 1 for constant flux
C                          = integer ratio of the tabular time step to
C                            to model the time step for the tabulated flux
                IF (MOD(ITTR,KFDG).EQ.0.AND.IFLX.LT.NFLX) IFLX=IFLX+1
                ITTR = ITTR+1
                P = (ITTR-KFDG*(IFLX-2))/FFDG
                QT = (1.-P)*FLUX(IFLX-1)+P*FLUX(IFLX)
                Q1 = QT*QCONST
                JJJJ = JJJJ+1
                TIME=JJJJ*AK
                IF (TIME.GE..01.AND.TIME.LE.20.) BLUD=(TIME-AK)/(20.-AK)*
     + BLOOD
                IF(TIME.GE.ETIME) Q1=-5.E-4*(T(1)-23.9)
                Z(1)=-F(1)*T(2)-((BK(1,1)+BK(2,1))/(2.0*H1*H1)-(DENS*
     +CP(1,1))/AK)*T(1)+Q1
                N=JINC-1
                DO J=2,N
                 F(J)=-BK(J+1,1)/(2.0*H1*H1)
                 G(J)=(BK(J,1)+BK(J+1,1))/(2.0*H1*H1)+DENS*CP(J,1)/AK
                 H(J)=-BK(J,1)/(2.0*H1*H1)
                 Z(J)=-F(J)*T(J+1)-((BK(J,1)+BK(J+1,1))/(2.*H1*H1)-DENS
     + *CP(J,1)/AK)*T(J)-H(J)*T(J-1)
                 IF (J.LE.3) Z(J) = Z(J)-1.675*H1/BK(J,1)*BLUD*(T(J)
     + -TEMPI0+TEMPB)
                END DO
                F(JINC)=0.0
```

```
            G(JINC)=(BK(JINC,1)+BK(JINC-1,1))/(2.0*H1*H1)+DENS*
     + CP(JINC,1)/AK
            H(JINC)=-(BK(JINC,1)+BK(JINC-1,1))/(2.0*H1*H1)
            DT=T(JINC-1)-(TEMPI0+TEMPB)
            Z(JINC)=(H(JINC)+(DENS*CP(JINC,1)/AK))*T(JINC)-H(JINC)*
     + T(JINC-1)-BK(JINC,1)*DT/H1**2
            W(1)=G(1)
            U(1)=Z(1)/W(1)
            DO J=2,JINC
             JM1=J-1
             SV(JM1)=F(JM1)/W(JM1)
             W(J)=G(J)-H(J)*SV(JM1)
             U(J)=(Z(J)-H(J)*U(JM1))/W(J)
            END DO
             T(JINC)=U(JINC)
             KK=JINC-1
             DO J=1,KK
              KMJ=JINC-J
              IF (IFLAG(KMJ).NE.1) THEN
               T(KMJ)=U(KMJ)-SV(KMJ)*T(KMJ+1)
               IF (JFLAG(KMJ).NE.1) THEN
                IF(T(KMJ).GE.BOIL) THEN
                 T(KMJ) = BOIL
                 IF (KMJ.NE.1) THEN
                  Q(KMJ) = BK(KMJ,1)*(T(KMJ)-T(KMJ+1))/H1
                 ELSEIF(KMJ.EQ.1) THEN
                  Q(KMJ) = QT
                 END IF
                 XTIME(KMJ) = 539.*H1/Q(KMJ)*WATER(KMJ,1)
                 ZTIME(KMJ) = XTIME(KMJ)+TIME
                 IFLAG(KMJ) = 1
                END IF
               END IF
              ELSEIF (IFLAG(KMJ).EQ.1) THEN
               IF (TIME.GE.ZTIME(KMJ)) THEN
                WATER(KMJ,1) = PCWATR
                CP(KMJ,1)=(CPCON(1)*WATER(KMJ,1)+CPCON(2))/(ROCON(1)*
     + WATER(KMJ,1)+ROCON(2))
                BK(KMJ,1) = (THCON(1)*WATER(KMJ,1)+THCON(2))/(ROCON(1)
     + *WATER(KMJ,1)+ROCON(2))
                IFLAG(KMJ) = 0
                XTIME(KMJ) = 0.
                JFLAG(KMJ) = 1
               END IF
              ENDIF
             END DO
C*******Interpolate extra temperatures between the surface and second node
             IF (NXTRA.NE.0) THEN
              IF (T(2).EQ.T(1)) THEN
C*******For constant temperature
               DO I=1,NXTRA
                XTMP(I) = T(2)
```

```
                END DO
               ELSEIF (T(2).EQ.T(3)) THEN
C*******Linear interpolation
                DO I=1,NXTRA
                 P = XTRA(I)/D2          !D(1) = 0.
                 XTMP(I) = (1.-P)*T(1)+P*T(2)
                END DO
               ELSE
C*******3-point Lagrange interpolation for equally spaced abscissae
                DO I=1,NXTRA
                 P = (XTRA(I)-D2)/D2        !D(1) = 0. (SURFACE)
                 XTMP(I) = .5*P*(P-1.)*T(1)+(1.-P**2)*T(2)+.5*P*(P+1.)
     + *T(3)
                END DO
               END IF
              END IF
              IF (ABS(ETIME-TIME) .LE. 0.5*AK) THEN
               DO I=1,JINC
                IF (IFLAG(I).NE.0) THEN
                 WATER(I,1) = (ZTIME(I)-TIME)/XTIME(I)*(WATER(I,1)-
     + PCWATR)+PCWATR
                 CP(I,1) = (CPCON(1)*WATER(I,1)+CPCON(2))/(ROCON(1)*
     + WATER(I,1)+ROCON(2))
                 BK(I,1) = (THCON(1)*WATER(I,1)+THCON(2))/(ROCON(1)*
     + WATER(I,1)+ROCON(2))
                END IF
               END DO
               DO I=1,JINC
                XTIME(I) = 0.
                IFLAG(I) = 0
                JFLAG(I) =1
               END DO
              ENDIF
              IF (T(1).GT.TMPMAX) TMPMAX=T(1)
              ITFLG = -1 !ITFLG SET TO 0 IF ANY TEMPERATURE .GE. 44 DEGREES
              DO J=1,JINC
               IF (T(J).LT.44.) THEN
                DW(J) = 0.
               ELSE
                ITFLG = 0
                IF(T(J).LT.50.) THEN
                 PL1 = PPL1
                 PLN1 = PPLN1
                 DE1 = DDE1
                 APL1 = APPL1
                 APLN1 = APPLN1
                 ADE1 = ADDE1
                 DWLN=PL1+PLN1-DE1/(T(J)+273.)
                 IF(DWLN.GE.87.0) DWLN = 87.0
                 DW(J) = EXP(DWLN)
                ELSE
                 PL1=PL2
```

```
                PLN1=PLN2
                DE1=DE2
                APL1 = APL2
                APLN1 = APLN2
                ADE1 = ADE2
                IF(J.LE.1) THEN
                 DWLN = APL1 + APLN1-ADE1/(T(1)+273.)
                 IF(DWLN.GE.87.0) DWLN = 87.0
                 DW(1) = EXP(DWLN)
                ELSE
                 DWLN=PL1+PLN1-DE1/(T(J)+273.)
                 IF(DWLN.GE.87.0) DWLN = 87.0
                 DW(J) = EXP(DWLN)
                END IF
               END IF
              END IF
             END DO
             IF (JJJJ.LT.2) THEN
              DO I=1,JINC
               SUM(I) = .5*DW(I)
              END DO
             ELSE
              DO I=1,JINC
               IF (SUM(I).LT.(1.0E38)) SUM(I)=SUM(I)+DW(I)
              END DO
             END IF
             IF (NXTRA.NE.0) THEN
              DO J=1,NXTRA
               IF (XTMP(J).LT.44.) THEN
                XDW(J) = 0.
               ELSE
                IF (XTMP(J).LT.50.) THEN
                 APL1 = APPL1
                 APLN1 = APPLN1
                 ADE1 = ADDE1
                ELSE
                 APL1 = APL2
                 APLN1 = APLN2
                 ADE1 = ADE2
                END IF
                IF (TP.EQ.999..AND.XTMP(4).GE.45.)
     + TP=TIME
                DWLN = APL1+APLN1-ADE1/(XTMP(J)+273.)
                IF(DWLN.GE.87.0) DWLN=87.0
                XDW(J) = EXP(DWLN)
               END IF
              END DO
              IF (JJJJ.LT.2) THEN
               DO J=1,NXTRA
                XSUM(J) = 0.5*XDW(J)
               END DO
              ELSE
```

```
                    DO J=1,NXTRA
                     IF (XSUM(J).LT.1.0E38) XSUM(J)=XSUM(J)+XDW(J)
                    END DO
                   END IF
                  END IF
                  EMTIME = AINT(1000.*(TIME+.00001))/100.
                  IF(TIME.LT.10..AND.AMOD(EMTIME,1.).EQ.0..OR.TIME.GE.10.
     + .AND.AMOD(EMTIME,10.).EQ.0.) THEN
                   WRITE(4,420)TIME,T(1),T(2),T(3),T(4),T(5),T(6),T(7),
     + T( 8),T(9),T(10),T(11),T(12)
                   PTS=PTS+1
                  ENDIF
                  IF (ITFLG.NE.0.AND.TIME.GE.ETIME.OR.JJJJ.EQ.M*100.OR.JJJJ
     + .EQ.1) CALL SUB12(TIME,T,XTIME,JINC,BLUD,CP,BK,NXTRA,XTMP,M,EM)
                 END DO
                 REWIND(4)
                 CLOSE(4)
                 DO I=1,JINC
                  W(I) = (SUM(I)-.5*DW(I))*AK
                 END DO
                 IF (NXTRA.NE.0) THEN
                  DO J=1,NXTRA
                   XW(J) = (XSUM(J)-.5*XDW(J))*AK
                  END DO
                 END IF
C*******Select W(J) and D(J) near W(J) =1
470              NN = 3
                 J=1
                 DOWHILE(J.LE.JINC)
                  JLT1 = J
                  IF(W(J).GT.1.) THEN
                   IF(J.EQ.JINC) THEN
                    NN=2
                    WRITE(3,440)(W(K),K=JLT1-1,JLT1+1)
                    WRITE(7, 440)(W(K),K=JLT1-1,JLT1+1)
440     FORMAT(/(1X,'W=',E20.5))
                    WRITE(3,450)(D(K),K=JLT1-1,JLT1+1)
                    WRITE(7,450)(D(K),K=JLT1-1,JLT1+1)
450     FORMAT(/(1X,'D=',E20.5))
                   END IF
                   J=J+1
                  ELSEIF(W(J).EQ.1.) THEN
                   MN=1
                   J=JINC+1
                  ELSEIF(W(J).LT.1.) THEN
                   IF (J.EQ.1) JLT1=2
                   IF (J.EQ.JINC) JLT1=JINC-1
                   WRITE(3,440)(W(K),K=JLT1-1,JLT1+1)
                   WRITE(7,440)(W(K),K=JLT1-1,JLT1+1)
                   WRITE(3,450)(D(K),K=JLT1-1,JLT1+1)
                   WRITE(7,450)(D(K),K=JLT1-1,JLT1+1)
                   IF (NXTRA0.NE.0.AND.JLT1.LE.2) THEN
```

```
              WRITE(*,460)
460     FORMAT(/,9X,'W=1 LIES ABOVE NODE 2.  INTERCOLLATING VALUES OF D'/
     + ,9X,'AND W COMPUTED FROM INTERPOLATED VALUES OF D AND',/,9X,
     + 'TEMPERATURE. ',/)
              WRITE(3,460)
              WRITE(7,460)
              WRITE(1)D(1)
              WRITE(2)W(1)
              DO J=1,NXTRA
               WRITE(1)XTRALG(J)
               WRITE(2)XW(J)
              END DO
              DO J=2,JINC
               WRITE(1)D(J)
               WRITE(2)W(J)
              END DO
              REWIND 1
              REWIND 2
              DO J=1,JINC
               READ(1)D(J)
               READ(2)W(J)
              END DO
              REWIND 1
              REWIND 2
              NXTRA0 = 0
              GO TO 470
             END IF
             J=JINC+1
            END IF
           END DO
         IF(MN.EQ.0) THEN
          NXTRA0 = NXTRA
          IF (W(JLT1+1).EQ.0..AND.NN.EQ.3) NN=2
          IF(W(JLT1-1).LT.1.0)THEN
            TD=0.0
            IERR=0
          ELSE
            CALL DEPTH(D(JLT1-1),W(JLT1-1),NN,TD,IERR)
C*******If Lagrangian interpolation didn't work, use linear interpolation
            IF(NN.EQ.3) THEN
              IF(W(JLT1-1).GE.1.0.AND.W(JLT1).LE.1.0.AND.(D(JLT1-1).
     +       GT.TD.OR.D(JLT1).LT.TD)) THEN
                NN=2
                CALL DEPTH(D(JLT1-1),W(JLT1-1),NN,TD,IERR)
              ELSEIF (W(JLT1).GE.1.0.AND.W(JLT1+1).LE.1.0.AND.
     +       (D(JLT1).GT.TD.OR.D(JLT1+1).LT.TD)) THEN
                JLT1=JLT1+1
                NN=2
                CALL DEPTH(D(JLT1-1),W(JLT1-1),NN,TD,IERR)
              ENDIF
            ENDIF
          ENDIF
```

```
            IF (IERR.NE.0) THEN
             WRITE(*,480)
             WRITE(3,480)
             WRITE(7,480)
480      FORMAT(9X,'ERROR IN SUBROUTINE "DEPTH". EXITING.'/)
             CALL ANOTHER(AGAIN)
            ENDIF
            IF (NN.EQ.2.AND.JLT1.EQ.JINC) THEN
             WRITE(3,490)MAXDIM
             WRITE(7,490)MAXDIM
490      FORMAT(/1X,'THE MODEL BLEW UP: DAMAGE > 1 AT NODE ',I2/)
             CALL SUB1020(W,JINC,D,TMPMAX,TD,TIME,TP)
            ELSE
             CALL SUB1020(W,JINC,D,TMPMAX,TD,TIME,TP)
            ENDIF
           ELSE
            TD=EXP(D(J))
            CALL SUB1020(W,JINC,D,TMPMAX,TD,TIME,TP)
           END IF
           CALL HARVARD(PROFILE,TFILE,SUMFILE,PTS)
          END IF
         ELSEIF(PROCED.EQ.1) THEN
          IF(AGAIN.EQ.0) THEN
           CALL SHOWVALUE(TEMPI0,DENS,FLUX,BL,AK,JINC,TEMPB,
     +    ABSORB,BOIL,PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,
     +    BLOOD,APL1,APLN1,ADE1,APL2,APLN2,ADE2,K,XTRA)
          ENDIF
         ENDIF
        END DO
        CLOSE(1)
        CLOSE(2)
        CLOSE(3)
        CLOSE(4)
        CLOSE(7)
        CALL COLORS
        DUMMY2=SETVIDEOMODE( $DEFAULTMODE )
        STOP
        END

        SUBROUTINE COLORS
           INCLUDE 'FGRAPH.FD'
           INTEGER*2 LOOP,LOOP1,DUMMY2
           REAL RND1,RND2
           DUMMY2=SETVIDEOMODE( $MRES256COLOR )
           DO LOOP1=1,10
           WRITE(*,10)
10       FORMAT(///,10X,'BURNSIM',///,15X,'BURNSIM',///,20X,'BURNSIM')
           DUMMY2=SETCOLOR(MOD( getcolor()+1, 16)) ! Set next color

            DO loop=1,3200
C*******Set a random pixel, normalized to be on the screen
             CALL RANDOM( RND1 )
```

```
            CALL RANDOM( RND2 )
            DUMMY2=SETPIXEL( INT2( RND1*320 ),INT2( RND2*200 ) )
           END DO
          END DO
          DUMMY2=SETVIDEOMODE( $MAXRESMODE )
          END

       SUBROUTINE WELCOME(PROFILE)
          CHARACTER PROFILE*8
          CALL CLEARSCREEN( $GCLEARSCREEN )
          WRITE(*,10)
10      FORMAT(//,9X,'WELCOME TO BURNSIM. TO BEGIN RUNNING THE PROGRAM,',
     + ' BURNSIM',/,9X,'FIRST NEEDS TO KNOW THE NAME OF THE FILE THAT',
     + ' YOU WANT TO',/,9X,'STORE THE OUTPUT DATA IN. THIS FILE WILL',
     + ' CONTAIN ALL OF THE',/,9X,'INPUT PARAMETERS AS WELL AS THE',
     + ' OUTPUT FOR EACH ITERATION THE',/,9X,'MODEL PERFORMS. THIS',
     + ' FILE CAN BE CALLED ANYTHING UP TO EIGHT',/,9X,'CHARACTERS',
     + ' LONG.',//,15X,'PLEASE ENTER A NAME FOR THE OUTPUT FILE: '$)
          READ(*,20)PROFILE
20      FORMAT(A8)
C*******Set up parameters for this run
          CALL CLEARSCREEN( $GCLEARSCREEN )
          WRITE(*,30)
30      FORMAT(///,9X,'NEXT BURNSIM WILL SHOW YOU THE PRESENT INPUT',
     + ' PARAMETERS.',/,9X,'UNDER THE LIST OF PARAMETERS YOU WILL SEE A'
     + ,' QUESTION ASKING',/,9X,'IF YOU WISH TO CONTINUE. IF YOU WANT',
     + ' TO EXIT THE PROGRAM AT ',/,9X,'THAT POINT, TYPE N. OTHERWISE',
     + ' TYPE Y.',///,9X,'TO CONTINUE ON TO THE LIST OF INPUT',
     + ' PARAMETERS TYPE A <CR>.')
          READ(*,*)
          END

       SUBROUTINE READDATA(TEMPI0,DENS,Q0,BL,AK,BOIL,ABSORB,JINC,
     + TEMPB,ITIME,ETIME,PCWATR,BLOOD,CP,BK,PL2,PLN2,PL1,PLN1,DE2,
     + DE1,APL1,APLN1,APL2,APLN2,ADE1,ADE2,WATER)
          REAL ITIME
          DIMENSION CP(12,2),BK(12,2),WATER(12,2)
          OPEN(UNIT=1,FILE='REN12.DAT',FORM='FORMATTED',STATUS='OLD')
          READ(1,10)TEMPI0,DENS,Q0,BL,AK,BOIL,ABSORB
10      FORMAT(7F10.5)
          READ(1,20)JINC,TEMPB,ITIME,ETIME,PCWATR,BLOOD
20      FORMAT(1I10,5F10.5)
          READ(1,30)(CP(J,2),J=1,JINC)
30      FORMAT(6F10.5)
          READ(1,30)(BK(J,2),J=1,JINC)
          READ(1,30)PL2,PLN2,PL1,PLN1,DE2,DE1
          READ(1,30)APL1,APLN1,APL2,APLN2,ADE1,ADE2
          READ(1,30,END=40)(WATER(I,2),I=1,JINC)
40        CLOSE(1)
          CALL CLEARSCREEN( $GCLEARSCREEN )
          END
```

```
      SUBROUTINE SHOWVALUE(TEMPI0,DENS,FLUX,BL,AK,JINC,TEMPB,
     + ABSORB,BOIL,PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,
     + NXTRA,BLOOD,APL1,APLN1,ADE1,APL2,APLN2,ADE2,K,XTRA)
         REAL ITIME
         DIMENSION FLUX(600),XTRA(8)
         CALL CLEARSCREEN( $GCLEARSCREEN )
         IF(K.NE.1) THEN
          WRITE (*,10)
10      FORMAT(///,30X,'SKIN DIFFUSION DATA'/,30X,'INPUT PARAMETER LIST')
         WRITE(*,20)TEMPI0,DENS,FLUX(1),BL,AK,JINC,TEMPB,ABSORB,BOIL
20      FORMAT(/,4X,'TEMPI0 = ',F10.5,6X,'DENS = ',F10.5,7X,'Q1 = ',
     + F10.5,/,4X,'BL = ',F10.5,10X,'AK = ',F10.5,9X,'JINC = ',I2,/,4X,
     + 'TEMPB = ',F10.5,7X,'ABSORB = ',F10.5,5X,'BOIL = ',F10.5,/)
         WRITE (*,30)PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,BLOOD
30      FORMAT(4X,'PL1 = ',F10.5,9X,'PLN1 = ',F10.5,7X,'DE1 = ',F10.1,/,
     + 4X,'PL2 = ',F10.5,9X,'PLN2 = ',F10.5,7X,'DE2 = ',F10.1,/,4X,
     + 'ETIME = ',F10.5,7X,'ITIME = ',F10.5,6X,'NXTRA = ',I2,/,4X,
     + 'BLOOD = ',F10.5,/)
         WRITE(*,40)APL1,APLN1,ADE1,APL2,APLN2,ADE2
40      FORMAT(4X,'APL1 = ',F10.5,8X,'APLN1 = ',F10.5,6X,'ADE1 = ',F10.1,
     + /,4X,'APL2 = ',F10.5,8X,'APLN2 = 'F10.5,6X,'ADE2 = ',F10.1,/)
         IF (NXTRA.GT.0) WRITE(*,50) (XTRA(I),I=1,NXTRA)
50      FORMAT(5X,'THE EXTRA NODES ARE: ',8F6.1)
        ELSE
         WRITE(3,10)
         WRITE(7,10)
         WRITE(3,20)TEMPI0,DENS,FLUX(1),BL,AK,JINC,TEMPB,ABSORB,BOIL
         WRITE(7,20)TEMPI0,DENS,FLUX(1),BL,AK,JINC,TEMPB,ABSORB,BOIL
         WRITE (3,30)PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,BLOOD
         WRITE (7,30)PL1,PLN1,DE1,PL2,PLN2,DE2,ETIME,ITIME,NXTRA,BLOOD
         WRITE(3,40)APL1,APLN1,ADE1,APL2,APLN2,ADE2
         WRITE(7,40)APL1,APLN1,ADE1,APL2,APLN2,ADE2
         IF (NXTRA.GT.0) WRITE(3,50) (XTRA(I),I=1,NXTRA)
         IF (NXTRA.GT.0) WRITE(7,50) (XTRA(I),I=1,NXTRA)
         K=0
        ENDIF
        END

      SUBROUTINE PROCEED(RESP,PROCED,AGAIN)
        CHARACTER RESP*1
        INTEGER PROCED,AGAIN
        WRITE(*,10)
10      FORMAT(//,15X,'DO YOU WISH TO CONTINUE? TYPE Y OR N '$)
        READ(*,20)RESP
20      FORMAT(A1)
        IF (RESP.EQ.'Y'.OR.RESP.EQ.'y') THEN
         PROCED=0
        ELSE
         PROCED=1
         CALL ANOTHER(AGAIN)
        ENDIF
        END
```

```
      SUBROUTINE ANOTHER(AGAIN)
         CHARACTER RESP*1
         INTEGER AGAIN
         WRITE(*,10)
10     FORMAT(//,15X,'DO YOU WANT TO DO ANOTHER RUN?  TYPE Y OR N '$)
         READ(*,20)RESP
20     FORMAT(A1)
         IF(RESP.EQ.'Y'.OR.RESP.EQ.'y') THEN
          AGAIN=0
         ELSE
          AGAIN=1
         END IF
         END

      SUBROUTINE DESCRIPT(DSCRPT,SUMFILE,TFILE)
         CHARACTER SUMFILE*8,TFILE*8
         DIMENSION DSCRPT(20)
         WRITE(*,10)
10     FORMAT(///,9X,'ENTER THE MODEL NAME OR DESCRIPTION (UP TO 80',
     +  /,9X,'CHARACTERS).  THIS INFORMATION WILL BE USED',/,9X,
     + 'AS A TITLE ON THE SUMMARY PAGE. '$)
         READ(*,20)DSCRPT
20     FORMAT(20A4)
         WRITE(3,30)DSCRPT
30     FORMAT(//,10X,'MODEL NAME OR DESCRIPTION: ',20A4)
         CALL CLEARSCREEN( $GCLEARSCREEN )
         WRITE(*,40)
40     FORMAT(///,9X,'NOW ENTER THE SUMMARY FILENAME (UP TO 8',
     + /,9X,'CHARACTERS).  THIS FILE WILL CONTAIN A',/,9X,'SUMMARY'
     + ' OF THE SIMULATION. '$)
         READ(*,50)SUMFILE
50     FORMAT(A8)
         OPEN(UNIT=7,FILE=SUMFILE,FORM='FORMATTED',STATUS='UNKNOWN')
         WRITE(7,30)DSCRPT
         CALL CLEARSCREEN( $GCLEARSCREEN )
         WRITE(*,60)
60     FORMAT(///,9X,'NOW ENTER THE TEMPERATURE FILE (UP TO 8',
     + ' CHARACTERS).',/,9X,'THIS FILE WILL CONTAIN A LIST OF THE',
     + ' TEMPERATURES',/,9X,'AT THE VARIOUS NODES DURING THE SIMULATION'
     + '. '$)
         READ(*,70)TFILE
70     FORMAT(A8)
         OPEN(UNIT=4,FILE=TFILE,FORM='FORMATTED',STATUS='UNKNOWN')
         END

      SUBROUTINE SUB12(TIME,T,XTIME,JINC,BLUD,CP,BK,NXTRA,XTMP,M,EM)
         DIMENSION T(12),XTIME(12),CP(12,2),BK(12,2),XTMP(8)
         WRITE(3,10)TIME
         WRITE(*,10)TIME,(T(I),XTIME(I),I=1,JINC)
10     FORMAT(/,45X,5HTIME=,F10.6:,T4,'T= ',6X,'XTIME='/('',2G12.4))
         WRITE(*,20)BLUD
20     FORMAT(1X,'BLUD =',F6.5)
```

```
          WRITE(3,30)(XTIME(I),I=1,JINC)
30      FORMAT(2X,'XTIME=',F10.5)
          WRITE(3,40)T(1),CP(1,1),BK(1,1)
40      FORMAT(2X,'T=',G16.5:,2X,'CP=',G16.5,2X,'BK=',G16.5)
          IF (NXTRA.NE.0) THEN
           DO J=1,NXTRA
            WRITE(3,40)XTMP(J)
           END DO
          END IF
          WRITE(3,40)(T(J),CP(J,1),BK(J,1),J=2,JINC)
          M=M+1
          EM = M
          END

        SUBROUTINE DEPTH(X,Y,N,TD,IERR)
C*******Inverse interpolation on two or three points to determine
C        threshold depth (predicted burn depth) using either Y or LOG(Y)
          DIMENSION X(1),Y(1),Z(3)
          IERR = 0
          IF (N.LT.2) IERR=-1
          IF(IERR.NE.-1) THEN
           DO 100 I=1,N
100        Z(I) = Y(I)
           Z0 = 1.
           IF (Z(1).NE.0..AND.Z(2).NE.0.) THEN      !USE LOGARITHMS?
            IF (N.EQ.3.AND.Z(3).EQ.0.) N=2
            Z0 = 0.          !USE LOGARITHMS
            DO 120 I=1,N
120          Z(I) = ALOG(Z(I))
           END IF
140        H0 = Z(2)-Z(1)
           IF (H0.EQ.0.) IERR=-1
           IF (N.NE.2.AND.IERR.NE.-1) THEN
            H1 = Z(3)-Z(2)
            IF (H1.EQ.0.) IERR=-1
            IF(IERR.NE.-1) H2 = Z(3)-Z(1)
            IF (H2.EQ.0.) IERR=-1
            IF(IERR.NE.-1) DZ3 = Z0-Z(3)
           END IF
           IF(IERR.NE.-1) THEN
160         DZ2 = Z0-Z(2)
            DZ1 = Z0-Z(1)
            IF (N.NE.2) THEN
             TD = DZ1*DZ2*X(3)/(H1*H2)-DZ1*X(2)*DZ3/(H0*H1)+X(1)*DZ2*DZ3
     + /(H0*H2)
            ELSEIF(N.EQ.2) THEN
180          TD = (DZ1*X(2)-X(1)*DZ2)/H0
            END IF
200         TD = EXP(TD)
           END IF
          END IF
          END
```

```
      SUBROUTINE SUB1020(W,JINC,D,TMPMAX,TD,TIME,TP)
        DIMENSION W(12),D(12)
        WRITE(3,10)(W(I),I=1,JINC)
10     FORMAT(/(1X,'W=',E20.5))
        WRITE(7,20)(W(I),EXP(D(I)),I=1,JINC)
20     FORMAT(/(1X,'W =',E20.5,5X,'AT DEPTH (IN MICRONS)=',G20.6))
        WRITE(3,30)TMPMAX
        WRITE(7,30)TMPMAX
        WRITE(*,30)TMPMAX
30     FORMAT(/,1X,'MAXIMUM TEMPERATURE = ',F8.3)
        WRITE(*,40)TD
        WRITE(3,40)TD
        WRITE(7,40)TD
40     FORMAT(/,1X,'THRESHOLD DEPTH = ',G20.4)
        WRITE(3,50)TIME
        WRITE(7,50)TIME
        WRITE(*,50)TIME
50     FORMAT(/,1X,'FINAL TIME = ',F7.2)
        IF(TP.NE.999.) THEN
         WRITE(3,60)TP
         WRITE(7,60)TP
         WRITE(*,60)TP
60     FORMAT(/,1X,'TIME TO PAIN IS ',F7.2,' SECONDS.')
        END IF
        END

      SUBROUTINE HARVARD(PROFILE,TFILE,SUMFILE,PTS)
        CHARACTER PROFILE*8,SUMFILE*8,TFILE*8,HGPLOT*1,HG*12
        INTEGER PTS
        WRITE(*,10)
10     FORMAT(///,9X,'TYPE A <CR> TO CONTINUE.')
        READ(*,*)
        CALL CLEARSCREEN( $GCLEARSCREEN )
        WRITE(*,20)
20     FORMAT(///,9X,'DO YOU WANT TO PLOT THE TEMPERATURES VS. TIME',/,
     + 9X,'TIME IN HARVARD GRAPHICS? TYPE Y/N '$)
        READ(*,30) HGPLOT
30     FORMAT(A1)
        IF(HGPLOT .EQ. 'Y' .OR. HGPLOT .EQ. 'y') THEN
         CALL PLOTHG(PTS,TFILE,HG)
        ENDIF
        CALL CLEARSCREEN( $GCLEARSCREEN )
        WRITE(*,40)PROFILE,TFILE
40     FORMAT(//,9X,'THE MODEL OUTPUT IS FOUND IN FILE: ',A10,/,9X,
     + 'USE "PRINT" OR "TYPE" AFTER YOU EXIT THE PROGRAM TO SEE IT.',
     + //,9X,'THE TEMPERATURES AT EACH NODE ARE IN FILE: ',A10,/,9X,
     + 'USE "PRINT" OR "TYPE" AFTER YOU EXIT THE PROGRAM TO SEE IT.')
        IF(HGPLOT .EQ. 'Y' .OR. HGPLOT .EQ. 'y') THEN
         WRITE(*,50)HG
50     FORMAT(//,9X,'THE TEMPERATURES FOR THE HARVARD GRAPHICS PLOT',
     + ' ARE IN FILE: ',/,9X,A12,'. USE "PRINT" OR "TYPE" AFTER YOU',
     + ' EXIT THE PROGRAM',/,9X,'TO SEE IT.')
```

```
        ENDIF
        WRITE(*,60)SUMFILE
60    FORMAT(//,9X,'THE SUMMARY PRINTOUT IS IN FILE: ',A10,/,9X,'USE',
     + ' "PRINT" OR "TYPE" AFTER YOU EXIT THE PROGRAM TO SEE IT.',///,
     + 12X,'TYPE A <CR> TO CONTINUE.')
        READ(*,*)
        CALL CLEARSCREEN( $GCLEARSCREEN )
        END

      SUBROUTINE PLOTHG(PTS,TPFILE,HG)
        REAL TIME(800),T1(800),T2(800),T3(800),T4(800),T5(800),
     + T6(800),T7(800),T8(800),T9(800),T10(800),T11(800),T12(800)
        INTEGER PTS
        CHARACTER HG*12,TPFILE*8
        OPEN(UNIT=4,FILE=TPFILE,FORM='FORMATTED',STATUS='UNKNOWN')
        DO I=1,PTS
         READ(4,40) TIME(I),T1(I),T2(I),T3(I),T4(I),T5(I)
     + ,T6(I),T7(I),T8(I),T9(I),T10(I),T11(I),T12(I)
40    FORMAT(13(F9.5,2X))
        END DO
        WRITE(*,10)TPFILE
        CLOSE(4)
10    FORMAT(/,9X,'THE TEMPERATURE DATA IS STORED IN FILE: ',A8)
        WRITE(*,20)
20    FORMAT(/,9X,'ENTER THE FILE TO STORE HARVARD GRAPHICS ',/,
     + 9X,'TEMPERATURES USING UP TO 12 CHARACTERS',/,9X,'INCLUDING'
     + ' THE ENDING .DAT ',$)
        READ(*,30) HG
30    FORMAT(A12)
        IF(PTS.LE.60) THEN
         OPEN(UNIT=5,FILE=HG,FORM='FORMATTED',STATUS='UNKNOWN')
         DO J=1,PTS
          WRITE(5,60) TIME(J),T1(J),T2(J),T3(J),T4(J),T5(J),
     + T6(J),T7(J),T8(J),T9(J),T10(J),T11(J),T12(J)
60    FORMAT(13(F9.5,2X))
         END DO
         CLOSE(5)
        ELSE
         INTERVAL=INT(PTS/60)
         OPEN(UNIT=5,FILE=HG,FORM='FORMATTED',STATUS='UNKNOWN')
         DO J=1,PTS,INTERVAL
          WRITE(5,80) TIME(J),T1(J),T2(J),T3(J),T4(J),T5(J),
     + T6(J),T7(J),T8(J),T9(J),T10(J),T11(J),T12(J)
80    FORMAT(13(F9.5,2X))
         END DO
         CLOSE(5)
        END IF
        END
```

APPENDIX C

REN12.DAT

This next file contains the initial values of the variables and constants required by BURNSIM. The file is REN12.DAT.

```
32.5,1.,3.54,0.22,0.01,100.15,0.613
12,4.5,80.,3.02,0.137,0.001
.5139,.8513,.8678,.8681,.8561,.8349,.8086
.7802,.7537,.7326,.7209,.7209
.00059604,.0012236,.0012541,.0012547,.0012322,.0011931,.0011439
.0010912,.0010419,.0010028,.0009810,.0008
2.24,239.47,1.46,147.37,80000.,50000.
.78,285.52,.60,117.43,93534.9,39109.8
.137,.72596,.75574,.75638,.73439,.69632,.64869
.598,.55081,.51364,.49298,.3
```

See the users manual for definitions of these abbreviations (eg. TEMPI0).

ROW 1	ROW 2	ROW 3
TEMPIO = 32.5	JINC = 12	Cp(1) = .5139
DENS = 1.	TEMPB = 4.5	Cp(2) = .8513
Q0 = 3.54	ITIME = 80.	Cp(3) = .8678
BL = 0.22	ETIME = 3.02	Cp(4) = .8561
AK = 0.01	PCWATER = 0.137	Cp(5) = .8561
BOIL = 100.15	BLOOD = 0.001	Cp(6) = .8349
ASORB = 0.613		Cp(7) = .8086

ROW 4	ROW 5	ROW 6
Cp(8) = .7802	BK(1) = .00059604	BK(8) = .0010912
Cp(9) = .7537	BK(2) = .0012236	BK(9) = .0010419
Cp(10) = .7326	BK(3) = .0012541	BK(10) = .0010028
Cp(11) = .7209	BK(4) = .0012547	BK(11) = .0009810
Cp(12) = .7209	BK(5) = .0012322	BK(12) = .0008
	BK(6) = .0011931	
	BK(7) = .0011439	

ROW 7	ROW 8	ROW 9
PL2 = 2.24	APL1 = .78	WATER(1) = .137
PLN2 = 239.47	APLN1 = 285.52	WATER(2) = .72596
PL1 = 1.46	APL2 = .60	WATER(3) = .75574
PLN1 = 147.37	APLN2 = 117.43	WATER(4) = .75638
DE2 = 80000.	ADE1 = 93534.9	WATER(5) = .73439
DE1 = 50000.	ADE2 = 39109.8	WATER(6) = .69632
		WATER(7) = .64869

ROW 10
WATER(8) = .598
WATER(9) = .55081
WATER(10) = .51364
WATER(11) = .49298
WATER(12) = .3

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